Final Technical Report

DOE Award Number: DE-FG36-05GO85050

Project Title: "Achieving the Security, Environmental, and Economic Potential of Bioenergy"

Recipient: The Aspen Institute Project Director: John A. Riggs

Executive Summary:

A group of business, government, environmental and academic leaders met in a dialogue and proposed a series of actions to promote the widespread commercialization of both corn and cellulosic ethanol to improve energy security, the environment, and the economy. Although the technical and economic feasibility of greater ethanol production was a component of the discussion, policy options for achieving this goal were the desired outcome. The group developed a series of recommendations involving improved crop yields, processing of biomass into ethanol, manufacture of more cars that can burn either ethanol or gasoline, and the provision of ethanol pumps at more filling stations. The report, "A High Growth Strategy for Ethanol," incorporated in full in this report, includes a discussion of the potential of ethanol, the group's recommendations, and the series of discussion papers commissioned for the dialogue.

Comparison of accomplishments with objectives:

Objective: To help develop broader consensus and clarity on the importance of a transition to sustainable and secure energy resources, the potential of bioenergy in that transition, and appropriate policy steps to accelerate the transition.

Accomplishment: The report of the stakeholder dialogue reflects a consensus on the rationale for and the elements of a politically feasible program to achieve more widespread use of ethanol in cars and light trucks.

Objective: To involve a broader group of stakeholders than is typically involved in discussions of bioenergy.

Accomplishment: The participants in the dialogue represented academics, agriculture, business leaders, energy experts, environmentalists, finance, government, and national security. (See participant list at end of report.)

Objective: To carry the conclusions of this dialogue to opinion leaders and into the policy arena.

Accomplishment: The report and recommendations were circulated to members of Congress, to the press, and by members of the group to their professional colleagues. It was also the subject of a Congressional breakfast briefing that attracted about 25 Senators and Members of Congress, and a roundtable discussion at the Aspen Institute. A news release was circulated to several hundred news outlets and Institute energy and environment participants. The report and release were posted on the Institute's web site. Tracking the influence of such a report is difficult, but anecdotal evidence indicates that it has been widely used.

Project activities

The project was carried out according to plan. The original hypothesis was that a diverse group of stakeholders, broader than the agriculture interests normally at the forefront of promoting the use of biofuels, could develop a rationale and policy recommendations for the rapid commercialization of ethanol that would attract support from a broad range of interests. The standard Aspen Institute methodology was used.

In the early months of the project, distinguished co-chairs for the dialogue were recruited, the agenda for the dialogue was narrowed and sharpened through conversations with experts in the field, and participants were invited. In part due to the high price of oil in early 2006 and in part due to the President's mention of cellulosic ethanol in the State of the Union address, interest was high, and most invitees accepted. In fact, the target group of 25 grew to 31 participants.

Discussion papers were commissioned and distributed to participants in advance of the meeting, on schedule, and formed the basis of the initial discussion. (These papers are included as appendices in the report that follows.)

The time allowed for the dialogue – two and a half days – proved to be dangerously short to achieve the ambitious goal of a consensus on policy recommendations. Compromises were achieved, however, through the effective guidance and time management of the co-chairs and by distinguishing between recommendations that achieved unanimous support and the few that were not supported unanimously.

Products

The written report of the dialogue and the commissioned papers constitute the primary product of the project. It was published and widely distributed in hard copy and was posted on the Aspen Institute's web site (www.aspeninstitute.org/ee) in a free, downloadable pdf, and an electronic news release was sent to hundreds of news outlets and Institute energy and environment participants. (Copy on following page.)

As a policy dialogue, the project did not develop any new technologies, techniques, inventions, patent applications, licensing agreements, data bases or computer models.

News Release – The Aspen Institute

One Dupont Circle, NW, Suite 700 • Washington, DC • 20036

www.aspeninstitute.org

Tel. 202-736-3849 • Fax 202-833-1813

FOR IMMEDIATE RELEASE

Contact: Alexandra Klaren
Public Affairs Coordinator
The Aspen Institute
Tel. 202-736-3848

DIVERSE GROUP URGES STRONG NATIONAL COMMITMENT TO ETHANOL USE

Washington, DC, June 6, 2006 – A group of business, environment, farm, and government leaders has proposed a series of actions to accelerate the use of ethanol as a replacement for gasoline, saying that "increasing reliance on oil is a costly bargain" that "threatens our economy, hamstrings our foreign policy and contributes to the degradation of our air, water, and climate."

In "A High-Growth Strategy for Ethanol," a report released today by the Aspen Institute, the diverse group calls for a national commitment to a "very ambitious" goal of producing 100 billion gallons per year of ethanol by 2025, the equivalent of half of today's U.S. gasoline consumption or nearly 25 percent of today's overall U.S. oil use. This would require an increase of conventional ethanol made from corn and the rapid commercialization of ethanol from cellulose, the fibrous material found in all plants, including non-food crops like switchgrass and wood chips.

According to former Congressman Thomas W. Ewing (R. IL), who co-chaired the meeting, "two-thirds of U.S. oil consumption is for transportation, and two-thirds of that is for cars and light trucks. With a few incentives that are small relative to the scale of the problem, our farmers and businesses can create a clean, domestic substitute for oil."

“We need to move beyond current blends of 10% ethanol or less and make E85, a blend of 85 percent ethanol and 15 percent gasoline, widely available,” said Nathanael Greene of the Natural Resources Defense Council, “and we need to ensure that the additional biomass is produced in a sustainable manner.”

To achieve the goal, the report recommends measures to expand the supply of feedstock available for ethanol production, developing refineries to convert cellulosic biomass to ethanol, increasing the number of vehicles capable of using E85 and the number of service stations distributing it, and assuring investors of a national commitment to reduce oil dependence even in the face of a drop in oil prices.

Among its key recommendations on ethanol production, the report called for fully funding existing legislative authorization for research and development to increase biomass yield per acre and to develop biomass-to-ethanol conversion technologies, increasing the Renewable Fuels Standard to 20 billion gallons by 2016, and providing a $0.75 per gallon production credit for ethanol from cellulose for five years.

To encourage ethanol use the report recommends a temporary financial incentive for automakers to cover the incremental costs of producing flexible-fuel vehicles, which can run interchangeably on gasoline or E85, and a temporary extension and increase in the existing tax credit for installing E85 pumps.

According to R. James Woolsey, a former Director of Central Intelligence and a co-chair of the meeting, “people in the business believe ethanol from cellulose will soon be able to compete with oil at $40 per barrel, well below most projections. But investors worry about an effort to drive the price of oil down temporarily to destroy alternative fuels, as was done in the mid-eighties and late nineties, and this led some in our group to recommend a flexible tax on oil designed to prevent the price from falling below $40.”

The report is available at www.aspeninstitute.org/eee/ethanol. For information contact Katrin Thomas at katrin.thomas@aspeninstitute.org or (202) 736-5857.

The Aspen Institute, founded in 1950, is an international nonprofit dedicated to fostering enlightened leadership and open-minded dialogue. Through seminars, policy programs, conferences and leadership development initiatives, the Institute and its international partners seek to promote nonpartisan inquiry and an appreciation for timeless values. The Institute is headquartered in Washington, D.C., and has campuses in Aspen, Colorado, and on the Wye River on Maryland's Eastern Shore. Its international network includes partner Aspen Institutes in Berlin, Rome, Lyon, Tokyo, and New Delhi, and leadership programs in Africa and Central America.

###

PROGRAM ON ENERGY, THE ENVIRONMENT, AND THE ECONOMY

A High Growth Strategy for Ethanol

The Report of an Aspen Institute Policy Dialogue

David W. Monsma, Rapporteur
John A. Riggs, Program Executive Director

For additional copies of this report, please contact:

The Aspen Institute
Publications Office
109 Houghton Lab Lane
P.O. Box 222
Queenstown, MD 21658
Phone: (410) 820-5326
Fax: (410) 827-9174
E-mail: publications@aspeninstitute.org
Web: www.aspeninst.org/EEE

For all other inquiries, please contact:

The Aspen Institute
Program on Energy, the Environment, and the Economy
One Dupont Circle, NW
Suite 700
Washington, DC 20036-1193
Telephone: (202) 736-5857 Fax: (202) 467-0790
E-mail: katrin.thomas@aspeninst.org
Web: www.aspeninstitute.org/EEE

The Aspen Institute
One Dupont Circle, NW
Suite 700
Washington, DC 20036-1193

Published in the United States of America in 2006
By The Aspen Institute

Printed in the United States of America

06-013
ISBN: 0-89843-453-X

Table of Contents

Foreword

Increased oil consumption is leading to greater economic and strategic vulnerability for the United States, and carbon dioxide emissions from the combustion of fossil fuels for transportation are a major contributor to potentially dangerous changes in the world's climate. These concerns are driving a search for alternatives to gasoline, and many experts consider ethanol one that can make a very large difference in a relatively short time.

In order to help develop broader consensus and clarity on the importance of a transition to sustainable and secure fuels for transportation, to consider the potential contributions of both corn ethanol and ethanol from cellulose, and to discuss appropriate policy steps to accelerate the transition, the Aspen Institute convened a group of leaders from government and the farm, environmental, energy, security and academic communities. The group met at the Institute's Wye River Conference Centers March 23 to 26, 2006.

The focus on ethanol was not intended to rank it as more important than other gasoline alternatives, and especially not more important than improved vehicle fuel economy. Indeed, there were advocates within the group for biodiesel, plug-in hybrid and hydrogen fuel cell vehicles, and all acknowledged that improvements in fuel economy would multiply the energy security and climate change benefits of all alternative fuels.

In keeping with the Institute's method of informed dialogue among people of diverse backgrounds and viewpoints, the group was challenged to weigh competing values and to approach policy issues holistically. A not-for-attribution rule encouraged candor and the exploration of new ideas, and the informal atmosphere and collegiality encouraged respect for different opinions. All participants were asked to approach the dialogue with the intention of identifying areas of agreement, to learn from each other and to explore the sometimes competing values underlying policy disagreements. After two and a half days of considering appropriate responses to the challenges identified, a set of recommendations was produced.

The dialogue was supported by a grant from the Biomass Program of the U.S. Department of Energy and was co-chaired by R. James Woolsey, Vice President of Booz Allen Hamilton and former Director of Central Intelligence, and Thomas W. Ewing, Chair of the USDA-DOE Biomass Advisory Committee and former Congressman and subcommittee chairman on the House Agriculture Committee. Their broad experience and insight helped guide the varied contributions of the diverse expert participants, bringing focus and perspective to a broad topic and guiding the development of the recommendations. Several of the participants contributed discussion papers, reprinted in this volume, which provided useful background for the dialogue and, we hope, for others seeking an understanding of the issues. Everyone at the table provided useful information and viewpoints, contributing immensely to the richness of the discussion.

The Aspen Institute is grateful to all of them, but this report is issued under the auspices of the Institute, and neither the sponsor, nor the meeting co-chairs, nor the participants are responsible for its wording. The group agreed to the recommendations in bold type starting on page 8, although with a lack of unanimity on the last three. The rest of the report is the staff's attempt to represent the views expressed at the meeting. Participants were not asked to agree to the exact wording, and some may differ with specific points. Participants were asked to speak for themselves and not for their organizations, but two felt the recommendations were sufficiently at odds with their companies' positions that they chose not to have their names included in the participant list. Their contributions to the dialogue were nevertheless valuable and are gratefully acknowledged.

David Monsma, the Program's Associate Director, served as rapporteur and admirably captured, distilled and organized the highlights of a free-ranging discussion. Katrin Thomas managed the administrative details of the Forum with grace and efficiency. Their help was invaluable and contributed greatly to a successful meeting.

John A. Riggs
Executive Director
Program on Energy, the Environment,
and the Economy

A High Growth Strategy for Ethanol

David W. Monsma
Rapporteur

A High Growth Strategy for Ethanol

Introduction

The United States depends on foreign sources for almost 60 percent of its oil supply, double the level of imports in 1972, the year before the Arab OPEC oil embargo. While enabling inexpensive transportation that has contributed to the nation's robust economic growth, this increasing reliance on oil is a costly bargain: high and volatile oil prices threaten our economy, our addiction to oil hamstrings our foreign policy and puts petrodollars in the pockets of terrorists and hostile regimes, and, like all fossil fuels, burning oil contributes to the degradation of our air, water, and climate.

Recent increases in the price of oil, driven by growing demand, especially from China, and by political risk in the Persian Gulf and other oil-producing areas, are harbingers of the rising economic threat. The Energy Information Administration in 2006 increased its 20-year price forecast for oil by roughly $20 a barrel from the year before, or about two-thirds. In the EIA reference case, the future price of imported crude never falls below $43 a barrel.

Two-thirds of U.S. oil consumption is for transportation, and two-thirds of that is for cars and light trucks. To reduce our dependence on oil, therefore, aggressive steps must be taken to reduce consumption of gasoline. A program reflecting national commitment and leadership is needed. Toward that end, we recommend that the

U.S. adopt a very ambitious goal of producing 100 billion gallons per year of ethanol by 2025, the equivalent of half of today's U.S. gasoline consumption or nearly 25 percent of today's overall U.S. oil use.

Ethanol can be used in existing cars in blends of 10 percent with gasoline. Flexible-fuel vehicles, capable of using either ethanol or gasoline, interchangeably, offer consumers the option of using blends of up to 85 percent ethanol. Conventional sources of ethanol, principally corn starch, are believed capable of producing 15-20 percent of the 100 billion gallons in our goal. The balance would have to come from cellulose, the fibrous material found in all plants, including non-food crops like switchgrass and wood chips. Advanced technology for converting cellulose to ethanol is currently being commercialized.

Our goal is substantially higher than many projections and assumes the adoption of most or all of the recommendations at the end of this report. The following steps are needed to achieve the goal and should be undertaken in parallel:

- We must greatly expand the total supply of feedstock available for ethanol production, largely through feasible improvements in yields per acre and the use of some Conservation Reserve Program land for energy crops.

- The conversion technology and refineries to process cellulosic biomass to ethanol must be developed, financed and built, and yields of ethanol per ton of biomass must increase.

- The number of vehicles capable of using high blends of ethanol and the number of service stations distributing such blends must be increased.

- Investors and developers in the nascent ethanol industry, as well as to gas station owners and auto manufacturers, must be assured that we are committed to a sustained effort to reduce our dependence on oil even in the face of a potential effort to drive down oil prices.

- The public needs to be better informed about the benefits of ethanol as a major portion of our transportation fuel mix.

Challenges and Opportunities

Security

Each of the oil crises of the last 35 years (triggered by the Arab OPEC oil embargo in 1973, the Iranian revolution in 1979, and the Iraqi invasion of Kuwait in 1990) caused significant economic harm to the U.S. and resulted in calls for reduced dependence on imported oil. Yet despite some fuel switching and improvements in efficiency, U.S. oil imports have increased from about 30% in 1972 to almost 60% in 2005. U.S. consumption continues to grow, while domestic production has declined steadily since 1970. World demand is expected to grow from today's roughly 85 million barrels per day to nearly 120 million barrels per day in 2025, and some analysts argue that most readily accessible conventional oil reserves have been discovered and production is about to peak.

Even before the 9/11 attacks and the war in Iraq, increasing U.S. and world dependence on oil from the volatile Middle East constrained our foreign policy options. As U.S. oil imports increase, global demand accelerates, and reserves outside the Persian Gulf region decline, the security risks of our oil addiction will grow. A transition to using ethanol in our cars, however, along with improved fuel economy and other alternatives, will help reduce U.S. dependence on oil and thereby decrease our vulnerability to oil price shocks and increase our foreign policy options, particularly if other nations follow suit.

Environment

There is widespread agreement among scientists that human emissions of carbon dioxide and other greenhouse gases are likely to have serious consequences for the world's climate. To prevent dangerous interference with the climate system, global carbon emissions over the next 50 years will need to be reduced by about 175 billion tons compared to a business-as-usual scenario. This will require a variety of actions in the U.S. and worldwide. More than 25 percent of manmade emissions of CO_2 in the U.S. are from transportation, and reducing the use of gasoline in cars is one of the largest contributions we can make. Compared to gasoline, ethanol made from corn is estimated to reduce greenhouse gas emissions by 20-30 percent and ethanol from cellulose – made from the stalks, stems and leaves of plants – by about 85 percent or more.

Using renewable fuels in transportation can also help reduce the air pollution associated with burning petroleum. With the adoption of sustainable production methods in the agricultural sector, the environmental impacts of farming practices can also be reduced.

Economy

Increasing global demand and a lack of spare production capacity, exacerbated by hurricane damage to U.S. production facilities and turmoil in some exporting countries, have contributed to recent high oil prices and threatened economic growth. Substituting domestically produced ethanol for a large portion of our gasoline use can dramatically reduce our oil imports and our balance of trade deficit. If oil averages $60 per barrel for 2006 and imports are over 12.5 million barrels per day, we will send about a quarter of a trillion dollars abroad for oil – nearly a third of last year's record trade deficit. Reducing our oil addiction can thus contribute to resolving some of our most difficult current economic problems as well as reduce our vulnerability to the economic devastation of future oil price shocks.

Substituting ethanol for gasoline can also begin to transform our system of agricultural price supports and land set-aside programs while creating jobs and stimulating the economy in rural areas. Transitioning some farm support programs toward assistance for energy crops would be more economically rational and would have significant energy and environmental benefits. World Trade Organization decisions declaring some current farm subsidies in violation of trade regulations may require that such a transition be initiated quickly. Reauthorization of basic agriculture programs, required in 2007, provides an opportunity.

Growing energy crops and harvesting agricultural residues will increase the value of farm output. Expanding the production of cellulosic biomass and adding it to increased production of corn will allow a substantial increase in ethanol production. The economic benefits will include additional and more diversified markets for both grain and energy crops that can help agriculture production achieve higher net returns, both locally and in the world economy. In addition to these benefits, investment in production plants located largely in rural areas will provide jobs and an increased tax base to help support local governments, schools and other public services. The benefits combined may even be able to slow the conversion of farmland into residential development and suburban sprawl.

The Potential of Ethanol

Biomass feedstocks for ethanol are abundant, varied and relatively inexpensive, and their potential for improved yields and processing potential are great. (See "Biotechnology for Biofuels Production," by Richard Hamilton, Appendix D.) With a concerted effort the U.S. can sustainably produce much more biomass for energy without diminishing our capacity to produce food. (See "Cellulosic Ethanol in an Oil and Carbon Constrained World," by W. Michael Griffin and Lester B. Lave, Appendix A, and "Impacts of Cellulosic Ethanol on the Farm Economy," by Bruce E. Dale, Appendix B.) With a corresponding effort, we can greatly reduce the cost of converting that biomass to ethanol, produce the cars to use it, and provide the fueling infrastructure. On average oil prices are projected to rise over time. Given sufficient development effort, ethanol can be expected to sell for less than gasoline, even taking into account ethanol's lower energy content per gallon.

Ethanol from corn and ethanol from cellulose are the same product. Ethanol in the U.S. is currently derived primarily from the starch in corn kernels. Ethanol from cellulose can be produced from a wide variety of feedstocks, including plants (switchgrass, sunflowers, hemp), plant waste (corn stover, cereal straws, sugarcane bagasse), and plant waste from industrial processes (sawdust, paper pulp, wood chips). Many experts expect switchgrass, a hardy, fast-growing, perennial crop that can be grown in large parts of the U.S., to be one of the major feedstocks of a mature ethanol industry.

Ethanol from corn is an established industry with substantial additional growth potential. The Renewable Fuels Standard passed by Congress in the Energy Policy Act of 2005 (EPAct 2005) requires the integration of 7.5 billion gallons of ethanol per year into the gasoline supply by 2012. We cannot, however, reach the goal of 100 billion gallons without ethanol from cellulose and without improvements in energy crop yields and the development of appropriate biorefineries. (See "Commercialization of Cellulosic Ethanol Facilities: A Financial Perspective," by Richard (Roy) Torkelson, Appendix E.) Ethanol from cellulose can also increase the environmental and other benefits already derived from corn ethanol. (See "Ethanol and the Environment: Delivering on the Promise of a Sustainable Biofuel," by Nathanael Greene, Appendix C.)

All cars and light duty trucks in the U.S. can already run on E10, a blend of gasoline containing 10 percent ethanol. There are also over five million flexible-fuel vehicles (FFVs) on the road today capable of running interchangeably on gasoline, E85 (a mixture of 85 percent ethanol and 15 percent gasoline), or any blend in between. Relatively few service stations sell E85, however, and many vehicle owners do not know that their cars can use it.

The principal challenge of achieving ethanol's potential is to increase concurrently feedstock production, conversion capacity, and availability of FFVs and E85 pumps so that a delay in one does not strand investments in the others. A second set of challenges is to correct misperceptions and manage expectations related to ethanol. For instance, the widely held perception in the U.S. that more energy is used to grow, transport and process the feedstock into ethanol than is contained in the ethanol itself is simply wrong. A growing number of peer-reviewed studies show that corn ethanol contains significantly more energy than it takes to produce it. Ethanol from cellulose will provide even higher energy returns. (See "Impacts of Cellulosic Ethanol on the Farm Economy," by Bruce E. Dale, in this volume; "Ethanol Can Contribute to Energy and Environmental Goals," Farrell et al, *Science*, January 27, 2006; and "Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present," by Roel Hammerschlag, *Environmental Science and Technology*, February 2006.) This misperception also reflects a misplaced concern, because producing and converting primary energy such as oil or coal into a usable product such as gasoline or electricity always requires large amounts of energy.

Similarly, we must manage the expectation that ethanol, or even ethanol from cellulose, is a silver bullet that can reduce gasoline prices overnight or single handedly solve all of our oil related challenges. It will be several years before we can start to produce a significant amount of ethanol from cellulose, so we must continue to grow the existing industry. Furthermore, improving the efficiency with which we use both gasoline and ethanol will always be the cleanest and fastest way for us to reduce our dependence on oil. In particular, improving the fuel economy of our cars and trucks is essential to managing the land requirements of ethanol.

The Brazilian Model

Brazil is on the verge of becoming independent of the need for oil imports due to its widespread use of flexible fuel vehicles and large-scale shift from gasoline to ethanol made from sugar cane. Although the U.S. and Brazilian situations differ in many respects – for example, ethanol produced from corn costs more and produces less energy per unit of input than ethanol from sugar cane – the speed of Brazil's adoption of flexible-fuel vehicles can be a model for the U.S. In the last three years, driven entirely by consumer demand, sales of flexible-fuel vehicles has gone from near zero to 75 percent of new cars. (See "Ethanol: Lessons from Brazil," by David Sandalow, Appendix F.) This shows the power of consumer demand when consumers are given a real choice.

We can also learn from Brazil's strategic mistake. Brazil launched a "Pro-Alcohol" program in the 1970s in response to the oil crisis. By the end of the 1980s, however, more than 75 percent of cars made in Brazil ran only on ethanol, leaving motorists in a lurch when oil prices fell and sugar prices rose sharply. Brazilian filling stations now offer pure ethanol and a blend of gasoline and 20 percent ethanol called gasohol, and the growing number of motorists with flexible-fuel vehicles use them interchangeably depending on price. Even though the early experience ended badly, Brazilians were left with the understanding that ethanol is a viable alternative fuel and quickly reached a tipping point when offered flexible-fuel vehicles that give them the power to choose. While it is hard to know what availability of flexible-fuel vehicles and E85 pumps would be needed in the United States, Brazil shows us that once we pass that tipping point, consumer choice can transform the market very quickly.

Research and Development

New technology to produce ethanol from cellulosic feedstocks points the way to a new generation of ethanol plants. The production chain consists of feedstock production, feedstock pretreatment, enzymatic hydrolysis, and fermentation. To make ethanol from cellulose competitive with gasoline, research is needed to improve the efficiency and economics of each portion of this chain *and* to integrate the chain. Emphasis therefore must be placed on the need to reduce costs by a combination of focused research and process demonstration at scale.

On top of fully funding R&D, a good deal of which is already authorized, financial investment and large scale commercial plants are needed to convert switchgrass and other cellulosic biomass to ethanol. The financial investments and market confidence needed to construct and pilot-test commercially viable biorefineries probably presents the most challenging single impediment to the new industry. Government assistance, in the form of loan guarantees or tax incentives for the first commercial plants, is needed to expedite the development of cellulosic ethanol production.

Recommendations

As part of trying to achieve the goal of 100 billion gallons of ethanol by 2025, the participants endorsed a series of recommendations aimed at the necessary prerequisites: an expanded supply of feedstock, adequate biorefineries to convert the feedstock to ethanol, sufficient flexible-fuel vehicles and E85 pumps, protection against an oil price collapse during the industry's infancy, and public education on ethanol. Except as specified below, all participants concurred in the recommendations. They are numbered for convenient reference, not to indicate any order of priority.

1. **Significantly increase sustainable biomass supply for ethanol a) by fully funding existing legislative authorization for research and development to increase biomass yield per acre and b) by increasing the total number of acres on which biomass can be sustainably grown.**

   Authority exists in the Biomass Research and Development Act of 2000, as amended by the Energy Policy Act of 2005, to support biomass R&D. This program should be fully funded at the authorized level of $200 million per year. Yet even if fully funded, additional R&D will still be needed to speed up advances in yield and deployment of new crops, harvesting technologies, and biomass handling strategies. State and federal governments, working with the private sector, should review the R&D needed and provide the leadership and financial support to increase, in a sustainable way, the supply of biomass for ethanol production.

   The U.S. government should provide direct support to farmers with specific incentives such as government contracts and loan guarantees for increasing biomass acreage dedicated to energy crops for ethanol around new biorefineries. Acreage in the Conservation Reserve Program that can be utilized for biomass harvesting under the authorities and restrictions in the 2002 farm bill needs to be identified.

2. **Catalyze greatly expanded ethanol production by providing appropriate government incentives to farmers and ethanol producers.**

   To commercialize production of ethanol from cellulose, adequate government incentives are needed both for the biorefineries and for the early production of dedicated energy crops to supply the biorefineries. This new ethanol-from-cellulose technology will require government support until such time as it is commercialized to a significant degree, perhaps 5-10 years. Dedicated energy crops may take several years to mature for harvest. Landowners and operators will need sufficient incentives to begin to grow and harvest these crops.

Building new ethanol plants or retrofitting existing ones to produce ethanol from cellulose will also require tax credits or loan guarantees initially. Public R&D investments will be needed along multiple technical pathways for pretreatment and conversion of cellulose.

3. **Institute measures to ensure that ecosystem integrity is maintained or enhanced with ongoing ethanol feedstock production.**

   Wild places should be protected from pressures to harvest biomass for ethanol, and agricultural and forestry ecosystems that are used to produce biomass must be maintained or enhanced even as we work to greatly increase overall production. The key measure of ecosystem integrity in this context is probably soil organic matter, which affects the quality of air and water. Other important metrics include mineral nutrient flows, water use and animal habitat. Field research and modeling should address the wide variety of ecosystems from which biomass might be produced and provide biomass producers with practical guidelines for the maintenance or enhancement of ecosystem integrity.

   The Department of Agriculture's Natural Resource Conservation Service and the Environmental Protection Agency should lead the development of an ecosystem analysis and comprehensive life-cycle approach to ethanol feedstock production. This is best accomplished in consultation with the conservation districts, state and private forestry agencies, departments of natural resources and state conservation districts for forested land. The

Natural Resource Conservation Service should then develop standards and specifications for biomass production and harvesting to be included in the field office technical guide.

With any future greenhouse gas credit generating system, there will be a need to differentiate sustainable from unsustainable production practices. A tracking system would help distributors and purchasers of ethanol to verify the as-yet-undefined sustainability aspects of its production. Additionally, diversification of feedstocks is necessary to avoid the impacts of natural vulnerabilities and catastrophic events on sustained biofuel production.

4. **Provide government support to promote new infrastructure and to improve existing infrastructure to harvest and store cellulosic biomass.**

   The feedstock production and transportation infrastructure necessary for biofuels deployment naturally supports a distributed system of smaller refineries than exist in the oil business. A future distributed fuel ethanol market will spread the opportunities for economic development and lead to greater national security in the form of a more decentralized infrastructure for transportation fuels.

   Existing authorization potentially supports R&D in infrastructure, handling and storage of cellulosic biomass, though funds have not yet been appropriated. A preprocessing and harvest demonstration grant program is authorized at $5 million per year for 5 years in Section 946 of the Energy Policy Act of 2005, and these funds must be appropriated. Rural Development grants and other USDA resources can be used to assist in an evaluation of the need. The necessary additional support identified by this evaluation should be funded with urgency.

5. **Carry out research and development to ensure that biomass supply for ethanol complements and does not undermine the production of food, feed and fiber and other plant-based products.**

Agriculture and forestry interests have long been associated with providing safe, abundant and affordable food, feed and fiber. As these industries transition to producing both energy crops and other plant based products, every effort must be made to continue to provide these traditional products. A comprehensive analysis must be initiated to fully examine the future roles of agriculture and forestry interests as they incorporate the new energy crop and plant products into their traditional roles and meet new and rapidly growing demand for cellulosic biomass. This work should be conducted jointly by USDA and DOE and is yet another important product that could be produced by a fully funded Biomass Research and Development Act.

6. **Conduct a study to explore the feasibility of establishing a Strategic Renewable Biofuels Reserve for ethanol production feedstocks.**

   A strategic renewable energy feedstock or ethanol reserve could bolster U.S. energy security by helping to maintain ethanol refineries and by preventing a loss of consumer confidence in ethanol when unforeseen circumstances cause a temporary unavailability of the feedstock or fuel. USDA and DOE should therefore conduct a feasibility study on a biofuels reserve, or the initial study could be funded by private sector groups. Depending on these findings, a strategic reserve for ethanol could theoretically work similarly to the Strategic Petroleum Reserve operated by DOE.

7. **Raise the Renewable Fuels Standard (RFS) to reflect the current growth rate of ethanol production and to reach a 20 billion gallon mandate by year 2016.**

   To ensure a continuing growth market for ethanol production, the current RFS production baseline should be raised to reflect the robust growth of the industry. The current Renewable Fuels Standard schedule should be expanded to reach a 20 billion gallon mandate by 2016. The vision is for ethanol to become cost-competitive, and expanding the RFS is a means to accomplish this goal. This will reassure farmers planting energy crops, investors in new biorefineries, manufacturers of flexible-fuel vehicles, and providers of retail ethanol filling stations that their investments will not be stranded.

8. **Fund the existing authorized efforts in research, development, demonstration and deployment of biomass-to-ethanol technologies.**

   Examples include fully funding and implementing the grant and loan guarantee programs for commercial projects as authorized under Section 1510, 1511(b) and 9006 of the Energy Policy Act of 2005, and fully funding and implementing the next generation of research and development and new technology pilots as authorized under Section 941 of EPAct 2005 - with urgency.

   Barring a collapse in oil prices, the existing corn ethanol industry will expand to its inherent limits without the need for much additional publicly funded research or demonstration. However, the 100 billion gallon per year goal of ethanol will require major advances in ethanol from cellulose. These advances will require focused research in key conversion areas and demonstration of conversion processes at sufficient scale to improve the economic viability of ethanol from cellulose production and reduce its risk.

9. **Provide incentives to ensure production of ethanol from cellulose.**

   • Under Section 942 of the EPAct 2005, provide a production credit of $0.75 per gallon for 5 years; or

   • Institute a reverse auction for the incentive needed to produce a certain amount of ethanol.

   The first handful of facilities that produce ethanol from cellulose will require special incentives to be built, but in order to encourage rapid deployment the next generation of plants will also need incentives. However, these later incentives should take a different form and should focus on production rather than investment and financing.

Section 942 of the Energy Policy Act of 2005 would provide a fixed incentive per gallon for the first plants and then would shift to allocating per gallon incentives through a reverse auction. Reverse auctions award incentives to bidders that request the least amount of incentive per gallon, thereby leveraging a fixed amount of government dollars to achieve the greatest amount of production. EPAct2005 authorized $250 million for Section 942 with the goal of reaching one billion gallons of production per year. This full amount should be appropriated, but it is insufficient to achieve the goal and should be increased over time to $1 billion.

10. **Provide a financial incentive to automakers to cover the incremental costs of flexible-fuel vehicle (FFV) production.**

Given the long life of vehicles already on the road, a large percentage of new vehicles sold must be FFVs if investments in ethanol production and ethanol pumps at filling stations are to be profitable. The Alternative Motor Fuels Act of 1988 (AMFA) currently provides an incentive for FFV production in the form of limited credits against Corporate Average Fuel Economy (CAFE) standards. New financial incentives should not be given for vehicles eligible for these credits, should be structured to reward early production of additional FFVs, and should be limited in time.

11. **Extend the existing tax credit for E85 pumps, raise the $30,000 cap on it, apply it per station, increase the percentage (from 30 percent) and phase the credit down over time.**

It is important for successful introduction, capital efficiency and commercial equity that the ratios of FFVs to total vehicles, and E85 pumps to total retail fuel pumps, grow together over time, especially during the start-up phase. Custom engineering pumps and converting gasoline pumps to E85 (removing aluminum, cleaning tanks, etc.) can be costly, particularly in congested areas or where permitting costs are high. An increased tax credit for a percentage of the cost should be provided to encourage more rapid installation of E85 pumps. The percentage of the costs for which the tax credit can be claimed should be increased now and then phased out over time.

12. **Update federal and California emissions test procedures to ensure equitable treatment of FFVs.**

    There are significant problems for testing E85 auto emissions under procedures designed for testing vehicles that run on gasoline. (Because of cold start problems, E85 in the winter can be E71, and E81 or higher in the summer.) Boutique blends vary by geographic markets and within some states. Therefore there is a need to evaluate all testing rules and procedures to ensure that E85 is not handicapped, while maintaining air quality standards. In particular, the California evaporative emissions test for gasoline vehicles is less protective of public health than the test for FFVs, and California and federal exhaust emissions tests did not contemplate E85 when they were developed.

13. **Develop improved fuel specifications for E85.**

    To allow engine calibration and to ensure customer confidence, EPA and the California Air Resources Board, in coordination with ASTM, should develop a benchmark for the range of high blend E85 fuel ethanol (e.g., different vapor pressure, seasons, cold start operation). The range for ethanol composition should be specified for season (e.g., a table in the ASTM specification gives a range). Although the product is always labeled E85, starting under cold weather conditions requires more hydrocarbons. The part of the blend that is not ethanol needs to be specified as well to assure that vehicle performance is not compromised due to low quality hydrocarbons being blended with ethanol to produce E85.

14. **Automakers or state departments of motor vehicles should share information about FFV density with E85 retailers, and automakers should collect and share information about pump locations with customers.**

Each state's department of motor vehicles has the VIN numbers of all registered cars, and from those numbers it is possible to identify where FFVs are concentrated. Making this information available to fuel retailers will allow them to install E85 pumps where FFV concentrations are greater. Automakers' sales information is a good proxy for density and should also be made available to fuel retailers.

Knowledge of the location of pumps would make it easier for drivers with FFVs to fill up with ethanol. This information should be collected by automakers from fuel companies or state agencies and made available to owners or potential buyers of FFVs.

15. **Pursue an auto industry commitment to produce FFVs at the maximum feasible pace, taking into consideration U.S. jobs and economic and vehicle life cycle issues.**

National security, oil dependence and climate change add to the urgency for the production of FFVs. Auto manufacturers could be persuaded to commit to aggressive FFV growth with the assurance that an entity like the National Highway Traffic Safety Administration, which understands the industry's economics, would be involved in setting and adjusting the goal.

16. **Educate the public on ethanol, including its benefits to national security, the environment, and the economy, and its impact on mileage and range.**

Motorists are not likely to know that ethanol has lower energy content than gasoline and are therefore likely to react negatively to the lower mileage and lesser range they achieve with E85. Eventually this is likely to be more than offset by the lower price of E85, but a simple chart in car owners' manuals and on pumps could simplify the calculation and help them understand that E85 can still be a better buy. They are also unlikely to understand how ethanol, especially combined with better fuel economy in general, can contribute to energy security, environmental protection, and economic development. A brief explanation of these benefits should be included in owners' manuals and publicized more generally by government agencies, ethanol manufacturers, and others concerned with these issues.

(Mandates recommended without unanimous support):

1. **Require that 60 percent of all cars and light-duty trucks shipped by each manufacturer be flexible-fuel vehicles by 2013, and**

2. **Require that any entity owning more than 25 retail filling stations provide one E85 pump at 3 percent of all of their stations in the first year of enactment and at an additional 3 percent of stations each year for nine additional years.**

In order to ensure that E85 pumps are available to fuel FFVs and to ensure that FFVs are available to provide customers for retailers who install pumps, it is important for the number of FFVs and the number of pumps to grow in balance. For this reason, and because of the benefits of expanding ethanol use rapidly, many members of the group felt that a minimum rate of growth should be established by law. Others, due to an opposition to government mandates or to confidence in the adequacy of the incentives provided by the recommendations above, did not agree. The proposed mandate on auto manufacturers is reasonably consistent with current and planned FFV production schedules of some manufacturers and therefore is a suitable target for all. The proposed mandate on service stations provides a more gradual expansion in recognition of the fact that not all stations need to have pumps to make E85 available to most motorists at most times. To avoid imposing an undue burden on small owners, the mandate would only apply to owners of a large number of service stations.

3. **Establish an oil price floor of $40 per barrel to protect the ethanol and other alternative fuels industries and to encourage fuel economy and conservation.**

   Oil prices are not likely to fall below $40 per barrel for an extended period of time and, once established, the ethanol industry is expected to be able to compete with gasoline produced from $40 per barrel oil. But the fear of a temporary oil price collapse, as occurred in 1985-1988 and again in 1997-99 and 2001-02, is a major disincentive to investment in ethanol production. A flexible tax on oil designed to prevent the price from falling below $40 would assure investors that oil exporting countries could not drive the price down to undercut this industry in its infancy.

   Although some participants in the meeting argued that the oil market is in no sense a free market and U.S. government intervention is therefore justified, others were opposed to such market interference. The latter participants believed that an expanded Renewable Fuels Standard could provide the same type of assurances to farmers, processors and others that there would continue to be a market for their products.

APPENDICES

Cellulosic Ethanol in an Oil and Carbon Constrained World

By W. Michael Griffin and Lester B. Lave*

The US has a unique window of opportunity. Three dollar a gallon gasoline prices experienced in the late summer and fall of 2005, our Middle East wars, and the probable imminent action of the World Trade Organization (WTO) to ban exports of subsidized corn have made the public and the Congress acutely aware of the politics of oil and its effects on our national security and economy. Global climate change due to greenhouse gas emissions has been getting more public attention to the point of President Bush advocating voluntary efforts to curb carbon-dioxide emissions. When the US becomes serious about addressing energy security, greenhouse gas emissions, and the sustainability of our transportation infrastructure, petroleum use will need to be cut substantially. Since we are a nation wedded to motor vehicles, we will need an alternative to gasoline, and attention is increasingly focusing on ethanol.

The US uses over 21 million barrels of petroleum per day, of which 60 percent is imported as crude oil or refined products. Ninety-five percent of oil is burned as fuel, directly or indirectly, of which two-thirds is gasoline. Our growing appetite for petroleum, together with demand growth in China, India, and the rest of the world, has pushed prices to their highest levels in a quarter century. Prices rose to just below $70 per barrel in August 2005. The futures

** Michael Griffin is Executive Director of the Green Design Institute and Lester Lave is Professor of Economics at the Tepper School of Business, Carnegie Mellon University.*

market reveals that experts are betting that oil will remain above $60 per barrel through at least 2012. Sensible policy requires the US to reduce the amount of energy used per vehicle-mile and adopt an alternative to gasoline. The Bush administration acknowledges a role for ethanol, and the President suggested the use of cellulosic ethanol derived from switchgrass in this year's State of the Union Address. The Energy Policy Act (EPAct) of 2005 mandates the use of 7.5 billion gallons of ethanol by the year 2012 and has policies to encourage the development of cellulosic ethanol including increased funding for R&D, loan guarantees for plant construction, and a 250 million gallon requirement for cellulosic ethanol use in 2013.

Most Members of Congress view ethanol support as a subsidy to the farmer, and thus there is no rationality underlying the volumes of ethanol required in EPAct. Although they represent virtually a doubling of the current corn ethanol volume, they do not begin to address seriously any of the issues raised above. This amount of ethanol won't even account for the expected growth of transportation fuel demand. Ultimately the Bush administration plans call for a hydrogen economy and hydrogen-powered vehicles. Our skepticism about when, and even whether, hydrogen could become the major fuel for the nation's light duty fleet is not the subject here. We simply note that even the most optimistic hydrogen proponent would leave us paying ever higher petroleum prices, causing continued environmental damage, and tailoring our foreign and defense policies to protect petroleum imports for decades to come. Putting all our eggs in the hydrogen basket would require large investments in expanding the current oil infrastructure due to the long lead time for hydrogen commercialization and would commit us to greater imports, higher prices, and greater dependence on the Persian Gulf until (and if) that technology were widely deployed.

The Competition for Ethanol

The world is not running out of oil in a time frame that will speed the development and acceptance of an alternative fuel. A myriad of studies argues the imminent peaking of conventional petroleum resources; others find enough resources to last decades. We find data from BP Statistical Review of World Energy (2005) particularly telling. The important statistic, reserves to production ratio, grew rapidly in the 80's, starting at just below 30 years to above 40 years. Intuitively this says the current reserves will last for 40 years at the current production rate. From 1990 through 2004 this indicator has varied only slightly within a range of around 39 to 42 years. The data indicate that during the 80's oil was being found much faster than demand was increasing. During the last decade we have been successful at finding as much oil as we used. The optimist will say that technology enhancements (seismic technology and direction drilling) have allowed us to keep pace and will do so in the future. The pessimist will say the easy oil has been found and it will be tougher and tougher to keep pace. Given these proven reserves, oil will be a competitor of any alternative fuel for decades.

The large amounts of bitumen in Canada's oil sands and the heavy oil in Venezuela and elsewhere are proof that we will not run out of liquid hydrocarbons any time soon. Canadian oils sands can be produced at or below an oil price of $25 per barrel; Venezuelan resources could cost more, but these two sources of non-conventional crude oil represent over 3 trillion barrels of oil in place, over twice conventional reserves. Unconventional oil comes with a price: increased water and energy use during recovery and a higher carbon content in the fuel, leading to increased greenhouse gas emissions, are important issues. Whether all the conventional and unconventional hydrocarbon resources will ever be produced seems doubtful. However, it makes little sense to argue that the lack of oil will require alternative fuels.

Other possibilities of fossil fuel use for transportation include the development of gas to liquids and coal to liquids. ExxonMobil and Chevron see gas to liquids as profitable at $45 per barrel oil. The processes are very capital intensive and sensitive to natural gas prices. In the US the high price of natural gas makes this option unattractive. In addition, a simple back of the envelope calculation shows that if all natural gas resources in the US were used to make gas to liquid fuels, we could fuel all US cars for a little over 4 years.

Internationally the price of gas and stranded gas reserves could make gas to liquids a viable source of imports to the US.

The other approach is coal to liquids, in which coal is transformed to synthesis gas and then converted by a gas-to-liquids process to transportation fuels. Economics are only sketchy, but if coal is available in large quantities for about \$1 per million Btu, this could become a competitive technology for \$60 per barrel oil. Even so we would use all of our coal reserves in 100 to 120 years fueling the entire US motor vehicle fleet.

Currently there is plenty of petroleum, but world demand is increasing rapidly, giving monopoly power to OPEC and large producers. Political turmoil, civil wars, terrorist action, or natural hazards will cause oil shocks with large price increases. Ultimately, however, fuel replacements such as ethanol will likely need to compete with oil prices that could be substantially below those of today due to development of alternative fossil fuel technologies. This is important because investors and consumers will want to be assured of a market for the alternative fuels before making substantial investments from production facilities to vehicles.

Greenhouse Gas Issues Limit Gasoline Use

Even with abundant petroleum, concern for limiting greenhouse gas emissions requires curtailing the use of petroleum and other fossil fuels. To achieve even modest emissions goals, the use of gasoline-diesel would have to be cut drastically. In order for the US to continue growing while slowing then eliminating the growth of greenhouse gas, CO_2 emissions per dollar of GDP would have to fall sharply. Assuming that GDP grows at 3 percent per year, emissions per dollar of GDP would have to fall by 75 percent in 50 years and by 95 percent in 100 years. Thus, a century from now, there cannot be any CO_2 emissions from motor vehicles and gasoline and diesel will not be permissible fuels, even if fuel economy were increased to 100 miles per gallon.

Cellulosic ethanol has the potential to begin the migration to a greenhouse gas neutral fuel supply over the next few years. The use of cellulosic ethanol simply recycles recent origin CO_2 by capturing the CO_2 as the plant grows and then releasing it as the ethanol is burned as a fuel. The fossil fuels used in growing the biomass (fertilizers, herbicides, tractors, etc.), transporting the biomass, and transporting the ethanol to the end user are offset to some extent by using excess energy generated from burning the lignin fraction of the biomass for grid electricity. Process energy for the production of ethanol is provided by lignin combustion. The midpoint of a range of values from a number of studies looking at life cycle CO_2 emissions from "wells to tank" showed on average that E10 could reduce CO_2 emissions compared to gasoline by 27 percent, and E85 by about 240 percent. Very recently new studies have shown even greater reductions in overall CO_2 emissions.

The cost of CO_2 abatement is important. There are many potential methods for point source emissions reduction, but mobile sources are more difficult. The potential of CO_2 reductions generated by producing and using cellulosic ethanol versus gasoline makes cellulosic ethanol an important approach. The cost of abatement is sensitive to the price differential between cellulosic ethanol and gasoline. For instance, in 2004 the average US wholesale price for ethanol was \$1.72. The corresponding gasoline wholesale price was \$1.27, making the cellulosic ethanol CO_2 abatement cost \$240 to \$270/ton of CO_2 for E85 and E10 respectively, taking into account energy density differences. However, in 2005 the gap between the gasoline and ethanol prices narrowed to a \$0.13 differential. The resulting abatement costs would then decrease to \$70 to \$77/ton CO_2, for E85 and E10. If the price of gasoline exceeds ethanol, which is entirely plausible, then the CO_2 abatement costs could be essentially zero.

Current Ethanol Use

Ethanol is currently supplied by an industry that consists of more that 90 corn ethanol plants with an annual production capacity of 4.4 billion gallons. The industry utilizes 1.3 billion bushels of corn, about 13 percent of the US corn crop. At average US corn yields of 148 bushels in 2005, approximately 8 million acres of corn was required, mainly in the Midwest. Corn is transported to the plants by truck and rail. The ethanol produced is shipped for blending with gasoline mainly via truck across the US.

This ethanol is used a fuel extender (E10 – a blend of 10 percent ethanol/90 percent gasoline), in oxygenated gasoline (at 7.7 percent), in reformulated gasoline (at 5.7 percent) or as an alternative fuel (E85). Currently ethanol is about 3 percent of the total "gasoline" usage for the US light duty fleet. Ethanol enjoys federal and, in some places, state tax incentives for ethanol-gasoline blends. Recent legislation, the Volumetric Ethanol Excise Tax Credit, provides for a Federal gasoline excise tax exemption on ethanol blends of $0.52 per gallon of ethanol. For example, a blender would receive a tax credit of $0.44 per gallon of E85, which most economists believe would be passed through to the consumer at the pump. It now applies to all blends of ethanol/gasoline. The goal of the Federal tax subsidy is to make the per gallon cost of ethanol equal to gasoline. All of the federal and state incentive programs were passed to increase the price of corn, to help farmers and to make a modest reduction in oil imports.

What We Need

To fuel the entire US auto and light truck fleet on E10, 15 billion gallons of ethanol per year would be needed (Table 1). A switch to E85 would require 166 billion gallons of ethanol. But corn ethanol production has limits due to co-product market saturation, reducing and possibly eliminating their production cost offsets for ethanol production. Also, corn has other uses. In our judgment, corn-ethanol production would be limited to 7 to 14 billion gallons. Thus, the US will need other sources of ethanol to embark on a serious reduction of petroleum use. In the immediate term this could come from imports, but ultimately most of the ethanol produced in the US will have to come from energy crops.

Fuel economy will play an important role in the future. To calibrate the potential for fuel savings via fuel economy improvements, the National Academy of Science's Committee on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards found that advanced technologies including direct-injection lean-burn engines, direct-injection compression-ignition engines, and hybrid electric vehicles could improve fuel economy by 20 to 40 percent. A 40 percent increase in fleet fuel economy would reduce the required amount of ethanol for E85 to 117 billion gallons, requiring just less the 100 billion gallons of ethanol to fuel the fleet.

Table 1

Ethanol required to meet various ethanol-gasoline blend levels[1]

Fuel	Required volume of blend	Required ethanol	Ethanol provided from corn	Ethanol required from other sources
	(billion gallons)			
E10	146	15	7-14	1-8
E85	195	166	7-14	152-159
E100	209	209	7-14	195-205

1 - Base year is 2004. Gasoline consumption was 141 billion gallons of which 4 billion gallons was ethanol.

It is widely recognized that land use will be an important issue in the ultimate size and acceptance of using energy crops for cellulosic ethanol. Without going deeply into the various process technologies, the anticipated yields from switchgrass (a potential energy crop) and subsequent conversion to ethanol could produce about 1000 gallons of ethanol per acre. An E85 fuel would likely be used, since E100 would have cold-start problems throughout much of the US. Thus with no increase in fuel economy or in vehicle miles traveled, the land required to produce enough energy crops to completely displace current gasoline consumption in the US is around 160 million acres. Doubling fuel economy would reduce this to 80 million acres, although increases in vehicle miles traveled would increase it.

Land use is very sensitive to energy crop yields and the amount of ethanol produced from each ton of crop. Although the land use requirements quoted here might seem high, we routinely plant 80 million acres of corn and another 80 million acres of soybean. Corn and soybean are good rotation crops and there is a market for the protein from the soybeans. Current R&D is developing methods for harvesting protein from switchgrass, reducing the need for soybeans. This could free acreage for energy crop production. More importantly, the future developments in cellulosic ethanol production and "learning by doing" with the first plants will greatly reduce land requirements

The Ethanol Possibilities

How do we get there from here? The first step in an orderly transition to a sustainable ethanol fuel supply is an increase in the production of corn ethanol. Even given a four-year lead time for development and construction of plants, corn ethanol could increase production more rapidly than envisioned by EPAct. Potentially, corn ethanol could provide as much as 14 billion gallons of ethanol. Building facilities to transform corn into ethanol helps develop the use of ethanol, paving the way for cellulosic ethanol in the future. The corn facilities can be fitted with a new "front end" at some future time to handle cellulosics, corn stalks and leaves, and switchgrass. The resulting ethanol is identical, regardless of the feedstock, so integrating more corn ethanol into the fuel supply is moving in the right direction. We envision a policy that could maximize this production.

The second step is encouraging imports of ethanol from Brazil and other Latin American countries. Although American agriculture will certainly want to protect its grip on the ethanol market, we need to use more ethanol than can reasonably be produced from corn. and creative policies can assure that imported ethanol displaces gasoline and not corn ethanol. Imports can help create an even larger market that American farmers can eventually serve with energy crops and cellulosic ethanol. The US would get the immediate benefits of using an alternative fuel, as well as shifting payments for imported energy from oil exporting countries to the less developed countries of our hemisphere, with all of the concomitant foreign policy benefits.

The third step is shifting ethanol production from corn to switchgrass. To realize this potential, we need to reenergize the stalled R&D effort on cellulosic ethanol. A small pilot plant was built at the National Renewable Energy Laboratory years ago, with little progress since then. At this point there are no commercial plants producing cellulosic ethanol. An aggressive plan is needed to move the current best concepts to pilot and then full-scale production. The near term goal should be set so that we (1) rapidly reduce our dependence on petroleum and (2) move toward the development of cellulosic ethanol. The ultimate endpoint in the amount of ethanol integration into the US fuel supply will simply be determined by developments in crop yields, cellulosic processing technology, and oil prices. If switchgrass yields and ethanol production efficiency exceed the modest levels used in this discussion, choices can be made to increase production or to diminish the ethanol footprint.

Oil at $60 per barrel, climate change and other environmental problems, excessive production of corn, the need to protect our farmland and strengthen our rural economy, and a foreign policy constrained by the need to protect our oil supply all point toward cellulosic ethanol as the principal source of our motor vehicle fuel in the future. There are many benefits, few costs, and no need to make expensive, irreversible commitments. This is a policy that makes sense and should be pursued with vigor.

Conclusions

The success of a strategy for adopting ethanol depends on many issues:

(1) The Government must demonstrate a commitment to the aggressive use of ethanol in its fuel mix;

   a. To assure markets, and
   b. To protect the developing alternative energy market from the inevitable rise and fall of oil prices.

(2) Maximize ethanol production from corn in the near term;

a. To begin rapidly to wean ourselves from gasoline and to develop the needed infrastructure, and

b. To make the farming community less threatened by the third recommendation.

(3) Permit imports of ethanol from developing countries;

a. To accelerate the transition away from gasoline,

b. To help exporting nations with their own internal development and to divert dollars from OPEC.

(4) Build first of a kind cellulosic ethanol production facilities

a. To provide much needed learning by doing.

b. To develop a "front end" that can then be deployed at current corn ethanol facilities.

(5) Target a cellulosic ethanol price to meet a market where \$35 to 45/bbl oil is likely.

Impacts of Cellulosic Ethanol on the Farm Economy

By Bruce E. Dale*

Size of the agricultural resource base for cellulosic ethanol

Background—Very different claims have been made regarding the potential size of the lignocellulose ethanol industry in the United States. The more pessimistic estimates tend to assume that agriculture and forestry will not change much in response to a large demand for biomass for ethanol production and also that yields of cellulosic biomass will also not change much. Neither assumption seems valid. Agriculture has changed greatly in the past in response to technology and societal demands. For example, prior to World War II less than a million acres of soybeans were harvested in the U.S. Wartime demand for protein and improved agricultural practices, combined with processing technology for producing soybean oil and protein meal, catalyzed the very rapid growth of soybean acreage to approximately 75 million acres today–about one sixth of our total cropland. The total amount of biomass available for cellulosic ethanol will depend on the yield and acreage devoted to such crops. We briefly examine both variables in turn.

Yield of Cellulosic Crops—Our existing major crops (corn, soybeans and wheat) have primarily been bred for high production of grain or oilseed. These breeding programs have been very successful. Corn yields have increased by over five fold (from about 30

* *Bruce Dale is Professor of Chemical Engineering at Michigan State University.*

bushels per acre to about 150 bushels per acre) in the past 50 years. These yield increases are due partly to increased inputs (agrochemicals, agricultural mechanization, etc.) and also to better plant genetics. We have never bred or developed cellulosic biomass species for high yields-there has been no demand for such cellulosic crops. For example, two promising perennial grass species for ethanol production are switchgrass and *Miscanthus*. The current highest reported yields for these species are between about 10 and 20 tons per acre per year. With the necessary agronomic research effort, it is entirely reasonable to believe that within a decade or two, the high yields can become average yields.

Land Devoted to Cellulosic Crops—We have about 450 million acres of cropland in the United States with approximately another 580 million acres of grassland pasture and range. Forest use land totals about 640 million acres, for a total of nearly 1700 million acres of land potentially available to produce feedstocks for ethanol production. Approximately 40 million of these acres are in the Conservation Reserve Program, a government program designed to take more fragile lands out of conventional grain or oilseed production. If we devote only 100 million acres to energy crop production and obtain an average of 15 tons of biomass per acre per year on that acreage and then convert that biomass to ethanol at 100 gallons per ton (approximately 85 percent of the theoretical maximum yield), we will produce 150 billion gallons of ethanol per year. This is equivalent to about 75 percent of the gasoline we currently use, taking into account ethanol's lower energy content per gallon.

Transition Issues—How can we start on the road to this promising future? Is there enough biomass to get this industry going in the absence of high yield biomass crops and large acreages devoted to cellulosic ethanol? Yes, there is. A recent comprehensive study by the Department of Energy and the Department of Agriculture identifies a sustainable supply of about 1.3 billion tons per year of biomass available in the near to mid term with proper management practices. The energy value of this much biomass is very nearly equal to 3.5 billion barrels of oil, which happens to be the energy content of the most oil the United States has ever produced in one year.

Food versus Fuel Concerns—Some are worried that large scale production of ethanol from cellulose will reduce food supplies in a hungry world. However, the actual world situation seems quite different than this picture. Recent analysis suggests that population growth rates are declining and that world population will stabilize by mid-century. China and India, once large food importers, are now much more nearly food self sufficient. Per capita production of wheat more than tripled in China from 1960 to 2000 while rice production per capita nearly doubled. India achieved less, but still very significant, growth in per capita food production. Also, most agricultural production capacity in the developed world does not feed humans directly, but rather feeds our livestock and humans then consume the meat, milk, eggs, cheese, etc. that the animals produce. Finally, large cellulosic ethanol productions facilities (called "biorefineries") will almost certainly coproduce animal feed just as biorefineries based on corn grain do now. Thus acreage devoted to cellulosic ethanol crops will probably produce both food and fuel.

Farm Subsidy Issues

Background—Direct government payments for agricultural price supports between 1995 and 2004 averaged $14 billion annually, providing six percent of gross and almost one quarter of net farm income. Payments in 2005 were about $24 billion. Loss of these subsidies would be a serious blow to farmers. Recently the World Trade Organization (WTO) ruled that U. S. cotton subsidies provide an unfair trade advantage to U. S. farmers and are illegal. Similar WTO challenges are expected to other U. S. price support programs for grains, oilseeds, rice, sugar and dairy products. Thus traditional government support programs for agriculture are seriously threatened.

Energy Payments Instead of Commodity Subsidies?—Energy payments would probably pass WTO muster, or at least not be challenged in the WTO. Currently, farmland conservation subsidies are considered by WTO as "green box" programs, meaning they are not subject to international trade sanction. Payments that provide and leverage the greatest environmental benefits are most likely to sustain challenges to their green box status. Moreover, bringing suit in the WTO is very expensive. Thus there would seem to be little incentive for most countries with a significant cellulose (or sugar or starch) to ethanol program to bring suit, since their own programs would likely be subsidized at least in their early years. Brazil in particular has subsidized its sugar to ethanol program to the tune of about $10 billion over the past 25 years (and thereby has avoided importing about $50 billion worth of petroleum). Far more countries will probably wish to produce ethanol for domestic consumption rather than export it, further minimizing the danger of WTO challenges.

Potential for Innovative Policy Measures—Innovative, system wide policy measures can accelerate the growth of cellulosic ethanol while protecting farm incomes and ensuring market discipline. For example, incentives to build the first generation of cellulose ethanol biorefineries should largely rely on the private sector's due diligence process to decide which proposed projects are built. The first generation of these biorefineries will be under extreme financial pressure. Farmer subsidies of $10 or $20 per ton of biomass supplied to the biorefinery could make the difference between profitable operation or failure.

Even more creative policy approaches suggest themselves in this time of transition. For example, farmers might wish to participate financially in the biorefinery to capture some of the value added to their raw materials, in much the same way that farmer coops are participating heavily in the rapidly growing corn dry mill industry. Farmers might choose to provide raw materials to the biorefinery at reduced cost, in exchange for some sort of equity in the plant. Or the government might "buy" partial farmer ownership in the plant in exchange for permanent elimination of subsidies on that farmer's production.

Impact on Corn Ethanol from Transition to Cellulosic Ethanol

Background—Currently about 4 billion gallons of ethanol are derived from corn grain in the U.S. The corn ethanol industry is slated to grow rapidly under the renewable energy standard included in the 2005 energy legislation, nearly doubling from the current 4.0 billion gallons per year to approximately 7.5 billion gallons per year. Corn farmers and ethanol producers are naturally concerned about the effect of a transition to cellulosic ethanol on the profitability of their farms and ethanol plants. These worries may be ill-founded. It seems far more likely that corn farmers and corn ethanol producers will benefit much more from, rather than be harmed by, a transition to cellulosic ethanol.

Some Relevant Factors—First, most farmers who produce corn for ethanol production can certainly grow biomass for cellulosic ethanol. High yielding, low input grass crops sold to the biorefinery at $50 per ton might well increase net farmer profit per acre compared with corn. Thus farmers need have no worry that they will not be able to participate in the supply side. Second, on the processing side, the existing capital investment in corn ethanol plants can probably be almost entirely recovered by converting such plants into cellulosic ethanol plants instead. Given their strategic location on rail lines, water transportation routes, etc., it is very easy to see corn ethanol plants becoming the nucleus of much larger cellulose ethanol biorefineries. One possibility is that corn ethanol plants would become the preferred location for converting solid cellulosic biomass to a liquid stream of concentrated sugars. This liquid stream would then be more easily shipped to much larger ethanol biorefineries.

Transition to Cellulosic Ethanol—Another important consideration is that corn ethanol producers are likely to be among the "first adopters" of cellulosic ethanol technology. Corn wet and dry mills produce significant amounts of cellulose-rich residues. As cellulose conversion technology develops, it is probable that these residues will be converted to ethanol in existing corn ethanol plants, which already have the infrastructure, supply system and much of the technology required. Given this head start in cellulosic ethanol, as expertise accumulates and production costs decrease, there will be a strong incentive to expand cellulosic ethanol production at these corn ethanol facilities. Expansion will probably occur by bringing in corn stover and/or dedicated biomass energy crops to what were formerly corn ethanol plants, making these facilities the cellulose ethanol biorefineries of the future. Alternatively, corn ethanol producers may eventually decide to use their facilities to produce more valuable biobased chemicals such as succinic acid, propanediol, lactic acid, etc. from corn rather than making ethanol.

Expanding the Benefits to More Farmers—Overall, many more farmers in many more states can expect to profitably produce cellulosic biomass than can competitively grow corn for ethanol. The "grass belt" is much broader geographically than the Corn Belt. Modeling done by the University of Tennessee predicts that farmers paid $40 per ton for switchgrass would plant 28 million acres of the crop and would produce 200 million dry tons. Obviously, they would produce even more at higher biomass prices.

If farmers were to receive between $40 and $50 per ton for cellulosic biomass yielding around 8 to 10 tons per acre, their gross receipts per acre would be comparable to those for corn. These biomass yields and prices are aggressive but not unrealistic. Each $10 per ton paid for biomass translates to approximately $0.10 per gallon for the resulting ethanol so that $50 per ton for the raw material translates into $0.50 per gallon of ethanol produced. As cellulose ethanol processing technology matures and processing costs decline, a reasonable goal is that processing will cost about half as much as raw material, so the ethanol will cost about $0.75 per gallon to produce, or about $1.10 per gallon on an equivalent energy basis with gasoline.

As farmers supply biomass for cellulosic ethanol the value of the remaining traditional crops would increase because reduced supply would generate better prices for these crop commodities. Total farmer net income would increase by well over $12 billion and these benefits would be distributed across the country with the largest increases occurring in the Plains states and the Corn Belt. Greater wealth and employment opportunities in rural America arising from cellulosic ethanol, both in crop production and the ethanol biorefineries, would benefit all farming communities, and the farmers who live there. Potential economic impacts of cellulosic ethanol on rural American communities are described more fully below. The cost of food should not be impacted much. Food prices are only affected slightly by crop prices received by farmers. But decreased or stabilized transportation fuel costs and enhanced energy security will benefit all Americans.

Energy Balance Issues

"Net Energy": A Brief History of the Controversy—For about the last 25 years a small but vocal group of ethanol critics has argued that corn ethanol, and more recently, cellulosic ethanol, has a negative "net energy". Simply stated, their argument is that more fossil energy is used in the production of ethanol, for example in fuel for producing, transporting, and processing the corn, than is delivered in ethanol's usable energy. Their viewpoint has been widely disseminated in the country and is a major perceived drawback to ethanol fuel. However, both the basic premise of the net energy argument and their analysis are wrong. Here is why.

Problems with the Net Energy Analysis—The critics' most recent such paper[1] concludes that corn ethanol has a -29 percent net energy and also that cellulosic ethanol from switchgrass has about -50 percent. Ethanol's net energy is defined as ethanol's heating value minus the fossil energy inputs required to produce the ethanol divided by ethanol's heating value. Ethanol's heating value is a scientifically fixed, known quantity and is about 68 percent that of gasoline. Thus the only potential point of controversy resides in the fossil energy inputs required to produce ethanol. Here these ethanol critics make three fundamental errors, one of premise and two of methodology. These errors are treated in turn.

All Btu are Not Created Equal—Energy markets clearly show us that all Btu are not created equal. Otherwise, we would not pay 12 times as much for a Btu of electricity (at $0.08 per kWhr) as we do for a Btu of coal (at $40 per ton). For accounting convenience, the proponents of net energy analysis assume that one Btu of energy available from any energy carrier is equal to a Btu from any other energy carrier. But is this assumption valid? A little reflection and analysis shows that it is not. We do not value energy *per se* but rather the services or "qualities" that the energy provides. For example, the energy in coal cannot directly light our homes. Coal must be converted to electricity in a power plant to provide many desired energy services. We always lose some energy in such conversion systems, including the conversion of crude oil to gasoline.

Data and Methods, and Lack of Comparisons—Recent independent high profile metastudies in the leading journals *Science*[2] and *Environmental Science and Technology*[3] have showed that the ethanol critics used some obsolete data and inadequate methods in their analyses. Further, the ethanol critics were wrong about how energy will be provided in a cellulosic ethanol plant. The metastudies also highlighted a very important fact from all studies of ethanol's energy balance, both pro and con. That fact is that corn and cellulosic ethanol both greatly extend existing petroleum supplies. If we "invest" a barrel of petroleum to produce ethanol we will get much more liquid transportation fuel (on an energy basis) than we will if we invest that same barrel to make gasoline. Thus using ethanol greatly extends the life of our existing petroleum reserves.

A final flaw in the arguments against ethanol's net energy is that they provide no comparisons with alternative energy sources. Comparisons of alternatives are central to science and sound policy decisions, and it is not difficult to do so in this case. Using precisely the same net energy methodology and assumptions of ethanol's critics, one quickly finds that gasoline has a net energy that is no better than -37 percent while electricity's net energy is about -235 percent, compared with corn ethanol's supposed -29 percent net energy. Thus ethanol is actually superior to other fuels in its "net energy".

What is an Appropriate Energy Efficiency Standard for Ethanol?—If "net energy" is a poor measuring stick for ethanol's energy efficiency, is there a better one? There is room for discussion on this issue, but two complementary standards suggest themselves. First, ethanol could be rated on its ability to displace petroleum, our most pressing *energy security* issue. One barrel of oil yields about 0.9 barrels of liquid fuels (gasoline, diesel, etc) when refined. It also requires about 0.1 additional "barrels of oil equivalent" in the form of both coal and natural gas to discover, produce, refine and distribute gasoline and diesel, etc. In contrast, one barrel of domestic petroleum "invested" to produce ethanol will give us about 20 barrels of oil on an equivalent energy basis. Thus investing a barrel of oil to make ethanol from corn gives us 22 times (20/0.9) more usable liquid fuel than making gasoline and diesel from the same barrel. The numbers for cellulosic ethanol are similar and can be expected to improve as biomass yields increase. Second, ethanol could be rated on the total displacement of fossil fuels (petroleum, coal and natural gas) required to drive a mile, our most pressing *climate security* issue. Cellulosic ethanol will reduce the life cycle greenhouse gas emissions required to drive a mile by over eight times compared to gasoline.

Rural Economic Impacts

Background—Of all the issues surrounding cellulosic ethanol, the economic impacts (and perhaps detailed assessments of the environmental impacts) are least studied. Thus only general statements providing some ranges of potential economic impacts can be provided at this time, mostly based on similar studies done for corn ethanol. These impacts can be divided roughly into: a) one time benefits from building the biorefineries, b) spending for continuing plant operations, and c) overall U.S. economic impacts.

One-Time Benefits—For sake of discussion, we will assume that 100 billion gallons of cellulosic ethanol capacity will be built over two decades. This is enough to displace about 70 billion gallons of gasoline per year, or roughly 50 percent of today's U.S. gasoline consumption. We further assume that these biorefineries will consume 1 billion tons of cellulosic biomass annually at a delivered price of $50 per ton, each biorefinery consuming 10,000 tons per day of biomass. Approximately three hundred such biorefineries will be needed to produce this much ethanol. Assuming they can be built for $1.50 per annual gallon of capacity, then $150 billion will be invested over 20 years to build the plants, or $7.5 billion per year. Using the data for corn dry mills, each dollar in plant construction would generate about $2.40 in a one time boost to the local economies as spending circulates, or about $18 billion per year in one time economic impact, much of it in rural America.

How realistic are these assumptions? A recent USDA/DOE study estimates that 1.3 billion tons of mostly cellulosic biomass can be sustainably produced on our lands, hence the 1 billion ton per year assumption above. A biomass price of $50 per ton is a reasonable target to allow attractive farmer returns and 10,000 tons per day is the approximate biorefinery size at which economies of scale are no longer very significant. Finally, a plant investment of $1.50 per gallon of annual capacity is comparable to that of recent corn dry milling plants for ethanol and seems a reasonable target for very large scale cellulosic ethanol plants, which are more complex than dry mills.

Benefits from Continuing Biorefinery Operations—Assuming that each plant spends about $165 million annually for biomass feedstock and that this raw material total represents 70 percent of total plant spending for all supplies and labor, then each plant will spend roughly $240 million per year for operations, or about $70 billion annually among all three hundred plants at the end of the twenty year transition period. Once again using data for corn dry mills, the local economic base surrounding these biorefineries would expand by about $140 billion per year and household income would expand by $25 billion annually, mostly in rural areas. The projected impact is very large, and would probably result in over 50 percent increase in total economic activity in affected areas. Assuming that each $200,000 in plant sales would support one new direct job in the agricultural and biorefining sectors, and an ethanol selling price of $1.00 per gallon, then a *half million new direct jobs* would be created, with a significant multiplier for indirect service and supporting jobs.

These numbers, although imprecise, are not at all unreasonable. Currently the U. S. fuels and chemicals industry employs about 900,000 people, many of them in commodity organic chemicals and fuels with total sales on the order of $1 trillion annually. As domestic oil and natural gas supplies have become more costly and scarcer, the fuels and chemicals industry is increasingly attracted to overseas locations where oil and natural gas are cheaper and supplies assured. As a result both domestic employment and economic activity suffer.

Overall Impacts on the U.S. Economy

As a full scale U. S. cellulosic ethanol industry takes hold and grows, it will transform our economy in at least two ways. First, the domestic fuels and chemicals industry will be revitalized, with many new jobs being created and new wealth generated. Given the wide distribution and bulky nature of biomass resources these new jobs and new wealth will largely be produced in rural America, rather than near oil production/importing sites on the coast. Second, the entire U. S. economy will benefit by a strengthened fuels and chemicals sector. We will be able to retain more of our fuel dollars at home and our economy will be much better insulated from shocks due to high petroleum prices and uncertain availability.

Footnotes

1. David Pimentel and Tad W. Patzek, "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower," *Natural Resources Research,* Vol. 14, No. 1 (2005), pgs. 65-76.

2. Alexander E. Farrell, et al. "Ethanol Can Contribute to Energy and Environmental Goals," *Science*, Vol. 311, 27 January 2006, pgs. 506-508.

3. Roel Hammerschlag, "Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present," *Environmental Science and Technology*, February 2006.

Ethanol and the Environment: Delivering on the Promise of a Sustainable Biofuel

By Nathanael Greene*

Introduction

The United States has just 3 percent of the world's oil reserves, and domestic production has been declining since 1970. Demand is soaring–driven largely by the transportation sector, which is 97 percent reliant on oil. As a result, we are forced to import 60 percent of our oil, and by 2025, we will import nearly 70 percent. Our dependence funnels billions of dollars to shaky and hostile regions, and defense and foreign policy experts increasingly point to our oil addiction as a national security emergency.

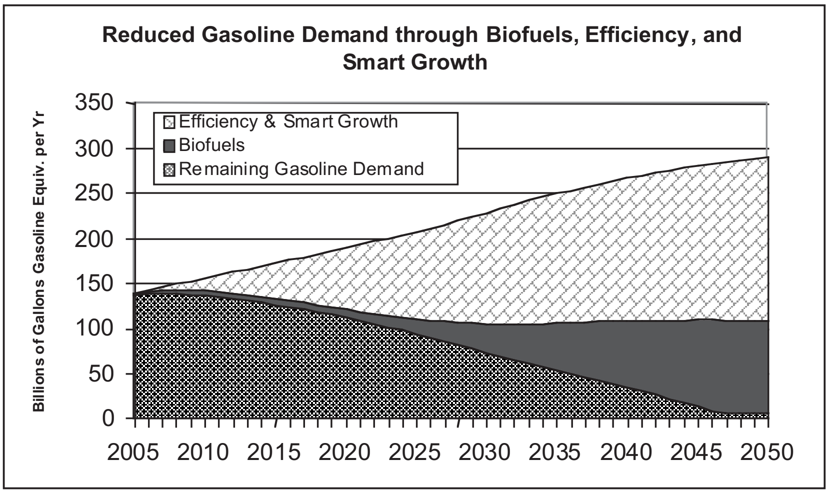
In addition America's cars, trucks, and buses account for 27 percent of U.S. global warming pollution, as well as soot and smog that damage human lungs, and oil price spikes have preceded each of the major recessions over the last 30 years. Oil is the Achilles' heel of America's security and economy and threatens the environment we want to leave to our children.

Biofuels, especially ethanol derived from the cellulosic part of plants rather than just the starch, are the most promising alternative fuels for the transportation sector. Replacing oil with biofuels would allow us to reinvest billions of dollars in our factories and farms. If we start now on an aggressive plan to develop and deploy advanced biofuels by 2050:

* *Nathanael Greene is Senior Policy Analyst at the Natural Resources Defense Council.*

- Cellulosic biofuels can displace nearly 8 million barrels of oil per day—nearly equal to all of the oil used by light-duty vehicles today;
- Biofuels can be second only to vehicle fuel economy improvements in the amount of oil they save;
- Biofuels, vehicle efficiency, and smart growth could eliminate virtually all our demand for gasoline; and
- Biofuels could reduce global warming pollution by 1.7 billion tons per year—22 percent of total U.S. emissions in 2002.

Figure 1. Biofuels Can Help Eliminate Our Demand for Gasoline by 2050.[1]



Biofuels can make this contribution based on just the land already used to grow crops while we continue to meet our other existing agricultural demands. Furthermore, growing the biomass needed to make biofuels could help dramatically reduce the environmental footprint of agriculture.

The bottom line is that there are pathways on which biofuels can make a major contribution to reducing our dependency on oil in a sustainable way. However there are also many pathways that are not sustainable. To understand the full promise of advanced biofuels and identify the policies necessary to realize this promise quickly and sustainably, it is crucial to understand the potential environmental impacts—positive and negative—associated with making and using biofuels.

There are three sets of environmental impacts that deserve particular attention. First, to make biofuels, we must first grow the biomass that will be the feedstock, and managing feedstock resources can impact the environment in many ways. Second, the amount of non-renewable energy and greenhouse gases must be accounted for and are most appropriately accounted for on a lifecycle basis. And third, we need to consider the air quality impacts of using biofuels in our cars and light-duty trucks.

Managing Feedstock Resources

In addition to energy and global warming pollution, agriculture can have a profoundly positive or negative impact on soil quality, water quality, water use, habitat, and land-use. There are crops and management practices that yield very large amounts of biomass per acre while dramatically reducing the environmental footprint of agriculture. For instances, switchgrass is a native perennial prairie grass. It does not need irrigation, requires less fertilizers and pesticides than traditional row crops, and provides a better habitat for wildlife. (See Tables 1 and 2.) As a perennial grass, it is mowed annually and thus there is no tillage, which reduces soil erosion. Finally and counter intuitively, it actually sequesters more carbon annually when it is harvested than when it is simply let to grow.

Table 1. Runoff from Corn, Soybeans, and Switchgrass[1]

	Typical Nitrogen application (Kg/hectare/year)	Percent of typical Nitrogen application that ends up in runoff	Nitrogen Runoff (Kg/hectare/year)
Corn	135	58%	78.8
Soybeans	20	81%	16.25
Switchgrass	50	19%	9.7

Table 2. Habitat Quality and Diversity for Different Crops[1]

Habitat Type[a]	Number of Breeding Pairs per 40 ha	Total Number of Breeding Species	Number of Sites Sampled
Dense switchgrass	182	10	8
Poor switchgrass	178	9	8
Reed canary grass[b]	246	9	6
Mixed warm-season grasses	126	13	7
Corn	32	5	16
Beans	22	2	9

a: Habitat types were categorized as follows: reed canary grass sites were not monotypes-they were fields where reed canary grass was the most common grass species (cover values ranged from 15% to 97%); dense switchgrass sites had >40% cover of switchgrass and <4% cover of other warm season grasses; poor switchgrass sites had <40% cover of switchgrass and <9% cover of other warm season grasses; mixed warm season grass sites had >72% cover of native warm season grasses other than switchgrass; bean and corn sites were on commercial bean (soy or snap) or corn fields, respectively.

b: Reed canary grass ranked highest in bird density primarily due to the influence of the large number of red-winged blackbirds (Agelaius phoeniceus L.) that nest in it.

Farmers have proven very innovative and capable at meeting market demand and reducing environmental impacts when they are given the right incentives. For instance, in recent years, corn farmers have dramatically increased yield per acre while reducing the amount of fertilizer used per bushel. Similarly many farmers are adopting low-till and no-till practices to protect their soil and soil quality. These practices and others have been driven both by the cost of inputs and by smarter and more effective conservation policies in recent farm bills.

To date our farmers and foresters have had essentially no market for biomass for biofuels. As this demand grows, it will put pressure on our agricultural lands and forests and could potentially encourage the use of types of biomass and management practices that are decidedly not renewable. So far, there has been a greater focus on biomass derived from croplands and while there are certainly ways to manage these lands that are unsustainable, a switch to high-yield cellulosic crops could make managing these lands easier. Forest lands represent a greater challenge since they are in general less intensively managed and wilder places. Thus increased demands for forest biomass pose a greater risk of environmental degradation.

Biofuels derived from forest biomass should be restricted to fuels made from trees removed from the immediate vicinity of homes, or pre-commercial thinnings where endangered forests are already protected and low-impact logging is faithfully implemented. Endangered forests, which include old growth forests, critical habitat for rare, vulnerable, or endangered species, and roadless areas are not a "renewable" resource; once cut down, they can take centuries to replicate. There is a role, however, for the federal government to support the removal of the most flammable wood biomass from communities at risk of forest fires. In addition, on a going-forward basis, where natural forests are converted to plantations or non-forest uses, fuels derived from the forest biomass and from the ensuing uses should be excluded from the definition of acceptable biomass for biofuels.

As we increase our use of biofuels, we should enable and encourage farmers and foresters to do better by the lands they manage. Eventually, as the market grows, consumers will demand and suppliers will market biofuels that are derived through more sustainable practices. This sort of market differentiation can be seen in almost every consumer product today. However, at a minimum, as the market develops, we must ensure that the production of biomass for biofuels does not increase environmental impacts of agriculture and forestry.

Improving the Efficiency of Biofuels Production

Efficiency is critical to every environmental aspect of biofuels and is crucial if biofuels are to play a major role in reducing our dependency on oil. Efficiency of land use (yield per acre), efficiency of conversion of biomass into biofuels (gallons per ton of biomass), efficiency of end use (miles per gallon), and efficiency of transportation (miles traveled per vehicle) all combine to determine the overall scale of each environmental impact from biofuels. Looking simply at the total land use gives a clear picture of how these factors combine. Under a business-as-usual scenario by 2050, our demand for gasoline will more than double from the current 140 billion gallons to 289 billion. Meeting all of this with current crops and current cellulosic conversion technologies would require over 1.7 billion acres of land.

Readily achievable advances in vehicle fuel economy, overall transportation efficiency, crop yields and conversion efficiency could reduce the land requirement to just 114 million acres. All of this land does not need to be solely devoted to producing biomass for biofuels. As the demand for cellulosic biomass is integrated into existing agricultural markets, farmers will find ways to sell as many valuable products as possible. For instance, corn farmers will happily sell corn stover (the cobs, stalks and leaves of the plant) as well as corn kernels, though they will have to weigh the income from the stover against the lost nutrients and soil organic matter and the need to protect their soil from erosion. Similarly, if the protein in a high cellulose-yield crop such as switchgrass proves to be equally or more valuable for animal feed than the protein in soybeans, then soy farms may choose to switch crops in order to be able to sell both cellulose and animal feed protein. A third example of integration involves meeting environmental goals. Switchgrass is currently grown on much of the farm land put aside in the Conservation Reserve Program (CRP) to protect soil, water, and habitat. It should be possible to harvest some of this while still meeting the goals of the CRP and thus make the program more financially self sufficient. These three measures alone would further reduce the amount of additional land needed to produce enough biofuels by 2050 to entirely eliminate our demand for gasoline to between 6 and 48 million acres. (See Table 3.)

Farmers will find other ways to integrate the production of cellulose into current markets. Other crops may well be able to achieve higher yields, and there are other sources of cellulosic biomass beyond just what can be produced from existing crop lands. Furthermore, our cars and trucks can certainly be more efficient than we have estimated here. The message should be clear though. Biofuels can either require an entirely unsustainable amount of land and thus be limited to a small role in an unsustainable future, or we can improve the efficiency of every stage of the lifecycle of biofuels, especially the fuel economy of our cars and trucks, and biofuels can provide virtually all our remaining demand.

The two other environmental impacts directly impacted by the overall efficiency of biofuels are fossil fuel energy use and global

Table 3. How Much Land to Meet Gasoline Energy Needs in 2050?[1]

	Gasoline Demand (billions gals of gas equiv)	Switchgrass Yield (dt/acre/yr)	Conversion Efficiency (Gals gas equiv/dry ton)	Land needed to meet gasoline demand (millions of acres)	
Production and efficiency gains					
Status quo in 2050	289	5	33	1753	
Smart growth and fuel economy by 2050	108	5	33	657	
Increase conversion efficiency	108	5	69	313	
Biofuels coproduction	108	5	77	282	
Increased switchgrass yield by 2050	108	12.4	77	114	
Alternative sources of land and biomass				Aggressive Integration	Partial Integration
Protein recovery	73 million acres of soybeans, 50% to 100% conversion to switchgrass			41	77
Corn stover	323 million tons of corn stover, 75% collected for biofuels			21	58
CRP land	30 million acres, 33% to 50% conversion to switchgrass			6	48

warming pollution. The corn ethanol industry has spent over two decades improving the efficiency of corn production and corn ethanol production and shifting the fuel used to drive the ethanol production process from coal to natural gas. The result is that the industry currently provides a modest but clearly positive energy return on the non-renewable energy invested and a reduction in global warming pollution relative to gasoline. Cellulosic biofuels production technology is expected to provide dramatically higher energy returns and larger greenhouse gas reductions.

Two recent peer-reviewed studies, one in *Science* and the other in *Environmental Science and Technology*, reviewed recent reports on the energy return of corn and cellulosic ethanol. Both studies show that there is actually a very strong consensus in the scientific community about the positive return from both corn and cellulosic ethanol. This is important because of an outdated public perception that the production process uses more fossil fuel energy than is available for use in the ethanol that is produced.

Cellulosic ethanol has a better energy return and global warming pollution profile in large part because cellulosic biomass arrives at the ethanol production facility combined with a renewable source of energy more than sufficient to drive the production process. Cellulose, a central component to most plant matter, is bound up with lignin, another major component. While lignin cannot be fermented into ethanol, it does have a significant energy value—enough energy in fact not only to power the entire ethanol production process but also to export energy either as electricity or, possibly, as biofuels using gas-to-liquids technology.

End Use

Currently ethanol is mostly used as an additive to gasoline in low blends up to 10 percent ethanol and 90 percent gasoline. However, the use of ethanol as an additive presents air quality challenges. NRDC research points to two key policy approaches to achieve clean air standards while advancing the use of biofuels and breaking our addiction to oil:

- Carefully manage the use of ethanol in small amounts as an additive to reduce harmful emissions.
- Push for a rapid transition to the use of ethanol as a gasoline alternative, with a focus on making it accessible to consumers.

Although originally introduced into gasoline specifications to combat ozone formation, ethanol in low blends can actually contribute to pollution. Studies by the California Air Resources Board and the Environmental Protection Agency (EPA) have concluded that low ethanol blends (E-5.7 in California) in the current fleet of vehicles increase ground-level ozone pollution by increasing emissions of two pollutants that lead to ozone formation—nitrogen oxides (NOx) and volatile organic compounds (VOCs)—more than they decrease the ozone-forming impact of a third pollutant—carbon monoxide (CO).

Nitrogen Oxides. Low ethanol blends boost the fuel-oxygen content and create an air-rich fuel, which, when combusted in traditional engines, results in higher levels of NOx. This effect is especially prevalent in vehicles built before the mid-1990s that cannot automatically adjust the amount of oxygen in the fuel before it is burned.

Volatile Organic Compounds. Low blends increase evaporative VOC emissions in two ways: by raising the vapor pressure of the blended fuel and by increasing "permeation." The change in vapor pressure can be controlled by changing the gasoline used in the blending. Permeation occurs when hydrocarbons from the gasoline migrate through the rubber and plastic components of a vehicle's fuel system, such as the fuel tank and hoses. Ethanol changes the properties of the fuel, allowing more VOCs to permeate the components and evaporate into the atmosphere. Recent studies suggest that if not accounted for by other changes in the fuel, this effect would substantially increase emissions. In Los Angeles, an area that currently suffers from a deficit of measures to reduce ozone pollution enough to meet clean air laws, these emissions could increase that deficit by about 10 percent.

Carbon Monoxide. Low blends of ethanol reduce CO emissions, but the ozone liabilities of permeation emissions outweigh the benefits from reduced carbon monoxide. While increased oxygen levels in fuels provide a beneficial effect of reducing the emissions of CO, this pollutant is only a relatively weak precursor to ozone.

Fortunately, newer vehicles, especially those that meet the current California Low Emission Vehicle II program and EPA Tier 2 emission standards, are equipped with engine and pollution control technologies that dramatically reduce these pollution impacts. Unfortunately, it takes 15 years or more for new vehicles to become the dominant technology on the road, so the air pollution liabilities with using low-blend ethanol will persist for many years unless proper safeguards are put into place.

By far the best way to avoid the air quality problems associated with ethanol is to use it as a high blend, such as E-85. High-blend ethanol fuels reduce evaporative emissions compared to low blends. E-85 is burned in flexible-fuel vehicles (FFVs) specifically calibrated to run on any fuel from regular gasoline to E-85. FFVs also have improved fuel systems that help minimize permeation and the latest oxygen-sensing technology to minimize NOx emissions. With the proper incentives, FFVs can ultimately take a large bite out of oil dependence.

There are about 5 million flexible-fuel vehicles on U.S. roads today, but due to the scarcity of E-85 pumps and a lack of awareness among owners, practically all of them are being run on gasoline. E-85 needs to be made more widely available, and the remaining 212 million gasoline cars and trucks should be replaced with FFVs. States can take the lead in making both happen.

Ethanol is good for blending, so it is likely to continue to be mixed into gasoline even in areas with severe air pollution problems. But any increase in ozone-forming pollution can and should be fully offset through more stringent and cleaner gasoline standards.

Because state and federal ambient air quality standards set thresholds for ozone levels, states are in a position to reach and maintain air quality standards by properly managing the use of ethanol blends. Some guidelines for state-level ethanol management are listed below:

- Prioritize aggressive measures to promote ethanol use in high blends, especially in areas that fail to meet ozone standards.
- Provide the maximum flexibility to refiners to blend ethanol in the winter, when smog formation is not a problem.
- Opt out of the provision that allows conventional (i.e., non-reformulated) gasoline to have higher vapor pressure (and thus higher evaporative emissions) when blended with ethanol.

Conclusion

Corn ethanol is currently providing us with modest but important environmental benefits, and it is building the market for an alternative to gasoline. Cellulosic biofuels promise to dramatically increase both the amount of biofuels we can sustainably produce and the benefits per gallon of biofuels that we use. But behind these general truths, the fact of the matter is that not all corn ethanol is created equal and not all cellulosic ethanol will be created equal.

There are feedstock resource management practices, ethanol production practices, and ways of using ethanol that are better for the environment than others. For instance, low-till and no-till harvesting practices are increasingly common and greatly reduce soil erosion and help maintain soil quality. On the production side, the current high prices of natural gas are driving many in the corn ethanol industry to consider powering their ethanol plants on coal, and they are pressuring the U.S. Environmental Protection Agency to allow greater air pollution to accommodate this shift. Meanwhile others are finding innovative ways to power ethanol plants off of animal waste, gasified biomass, and solar power.

Whether these types of measures are adopted can greatly increase or entirely eliminate the benefits of ethanol. To maximize the benefits from biofuels as we push the technology and market to develop quickly, we need to develop clear metrics of the performance we want from ethanol. The obvious ones are greenhouse gas reductions and oil displacement, but many consumers and policy makers will also demand that biofuels actually improve water, air, soil, and habitat quality. They may also want to be able to buy locally produced ethanol or ethanol from farmer-owned production facilities. This means not just developing certification systems but also the transparency and accountability in the market so that consumer preferences and standards can be directly relayed to farmers and producers.

The risks that our addiction to oil poses to our economy, our national security, and our environment are simply too great too leave the evolution of biofuels and our transportation energy needs to chance. We need to develop the technology from crops through to cars and pumps, push this technology from the labs to the consumers, and guide the market so that we do in fact take a sustainable path to delivering on the promise of biofuels.

1. Greene N. *et al.*, "Growing Energy: How Biofuels Can Help End America's Dependence on Oil," Natural Resources Defense Council, December 2004.

Biotechnology for Biofuels Production

by Richard Hamilton*

Improved conversion processes

Recent technology advancements in cellulosic biomass conversion technologies, combined with high fossil fuel prices, have rekindled interest in the potential of cellulosic biofuels. Biotechnology has already reduced the cost of conversion and can continue to do so.

Most of the carbohydrate in a plant is in the form of cellulose and hemicellulose, which is primarily found in the leaves, stems, and stalks of plants, rather than the starch or sucrose found in fruit or seeds such as corn kernels. Digestion and subsequent fermentation of cellulose and hemicellulose can yield significantly higher amounts of ethanol than can be generated from starch or sucrose alone. However, cellulose has been historically difficult to break down and ferment in an economically attractive way. Enzymes, or cellulases, which catalyse the breakdown of cellulose, have been isolated from several different organisms, including fungi. However, the purification of enzyme from these sources is prohibitively expensive, on the order of $5.50 per gallon of ethanol produced. Genetic engineering or biotechnology has already played a key enabling role in the development of cellulosic biomass conversion technologies by dramati-

* *Richard Hamilton is the President and CEO of Ceres, Inc.*

cally reducing the cost of cellulase production from about $5.50 per gallon of ethanol to $0.10-15 per gallon of ethanol.

Future biotechnology-based developments in processing technology will likely include:

- Improved cellulase and hemicellulase production economics via microbe or plant-based production systems,
- Improved fermentation strains that efficiently utilize both hemicellulose (C5) and cellulosic (C6) sugars
- Consolidated bioprocessing microbes which combine the ability to break down cellulosic materials with the ability to efficiently ferment various sugars to ethanol.

Some or all of these approaches will be combined to further reduce the cost of biorefining reagents as well as ultimately impacting biorefinery design and capital expenditure requirements.

Improved feedstocks

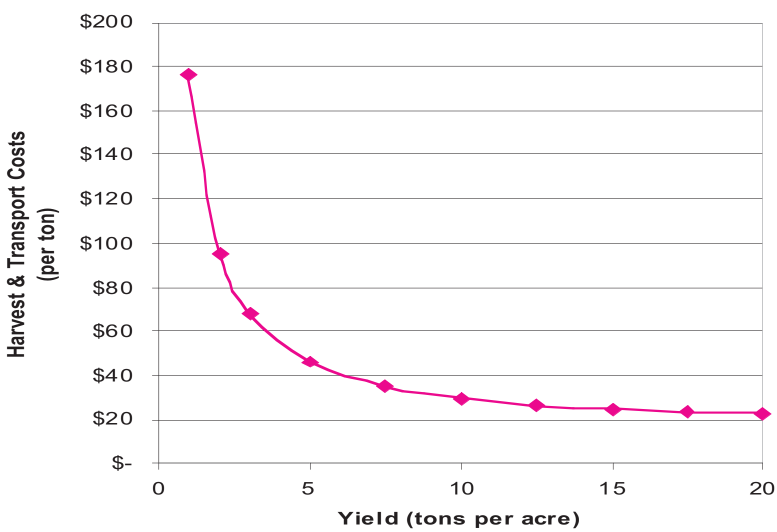
The next horizon for biotechnology will be its impact on the development of improved biomass feedstocks for biofuels production. Modern biotechnology can take several forms and includes:

- marker-assisted breeding – the use of genomics to generate DNA markers associated with specific plant phenotypes;
- precision-breeding – the use of recombinant DNA technology to reintroduce plant genes into a plant under different regulation; and
- transgenesis – the ability to transfer genes between species.

It is worth noting that the use of biotechnology in agriculture has expanded dramatically in the past decade with over 1 billion acres of genetically enhanced crops planted worldwide. Along with increased yields and improved farm economics these technologies have also enabled demonstrable environmental benefits in the form of reduced soil erosion and reduced application of chemical pesticides.

Many believe that the earliest iterations of cellulosic biorefineries will utilize crop residues such as corn or wheat stover as a feedstock. While these food crop residues can be utilized as feedstocks, it is worth remembering that these crops have been bred for the past 8,000 years for increased grain production, not increased biomass production. Perhaps the best way to approach the development of a cellulosic feedstock is to consider what characteristics an ideal feedstock would have and then ask what combination of germplasm and technology developments can get us to the desired outcome most quickly and cost effectively. An ideal biomass feedstock would certainly have the following characteristics:

- **High yield density** (increasing tons per acre) – High biomass yield density is the single most important characteristic a biofuel feedstock can have. Feedstock cost (at the refinery gate) is the single largest cost element in biofuel production. Harvesting and transportation costs are the single largest component of feedstock cost. As demonstrated in the table below there is an exponential relationship between feedstock density and harvest/transportation costs.



Biotechnology can impact yield density by altering plant physiology, plant architecture, and photosynthetic efficiency. Preliminary results indicate that biomass yield increases of >300 percent in some grass species can be achieved via genetic engineering, making the goal of a 15 ton per acre feedstock well within the realm of feasibility.

- **Low agronomic inputs** (reducing dollars per acre) – In order to increase the net energy per acre created, one must limit the energy inputs that go into growing a biomass crop. One obvious opportunity for lowering input costs is to use perennial versus annual crops to eliminate fuel usage associated with annual planting. Another opportunity is to limit the use of herbicides and pesticides and the associated fuel usage to apply them. Further gains in net energy per acre can be created through reduced fertilizer applications and reduced irrigation requirements.

  Biotechnology has demonstrated its ability to reduce agronomic inputs such as herbicide and pesticides. Progress is rapidly being made on traits which enable crops to take up and utilize nutrients more efficiently, thus enabling them to be grown with less fertilizer.

- **Able to grow on marginal land** (expanding usable acreage) – Much of the very best farmland is dedicated to food production. Producing biomass crops on so called "marginal" acres, e.g. land that is too dry, or with poor soil characteristics, can increase the scale of biofuels production without competing for food production acres. Biotechnology is enabling the development of drought, heat, cold and salt plants as well as plants that can thrive on a variety of different soil conditions.

- **High energy content** (increasing gallons per ton) – Different plants vary in their relative content of cellulose and hemi-cellulose material. For the purpose of a biomass feedstock plant, a high level of cellulose and hemi-cellulose content would give a greater fermentation yield or more gallons of ethanol per ton of biomass. This means more net energy per acre and more revenue for the same scale biorefinery. The use of biotechnology to achieve these traits is already underway in a number of commercial and academic laboratories.

- **Improved processing characteristics** (decreased cost per gallon) – The recalcitrance of cellulosic biomass to digestion and fermentation remains a significant obstacle to the large scale adoption of cellulosic biorefineries. Designing a feedstock plant with improved processing characteristics such as decreased lignin levels would result in an improvement in the overall economics.

In summary, there are multiple areas where the application of modern biotechnology can significantly impact the economics of biofuel production. While the use of agricultural residues will certainly have a role in the initial adoption of cellulosic biomass technologies, the application of biotechnology to perennial grass species such as switchgrass, sugarcane and *miscanthus* over the next several years will result in a more economically competitive and environmentally friendly biofuel feedstock, and will enable the biofuel industry to scale to a point where it can meet a significant percentage of global transportation fuel demand.

Public policy to accelerate the development of biomass feedstocks should focus on:

- Loan guarantees and other incentives to ensure cellulosic biorefineries get built,

- A fast-track process for regulatory approval of dedicated energy crops,

- Crop subsidies and loan programs to put biomass crops on equal footing with other major row crops, and

- Carbon credits or trade system to put biofuels on equal footing with fossil fuels.

Commercialization of Cellulosic Ethanol Facilities: A Financial Perspective

By Roy Torkelson*

The US Department of Energy expends significant amounts of government money conducting extensive research into biomass technologies in cost sharing arrangements with private sector industries and at National Laboratories. A high level of frustration has been mounting over the inability to deploy proven research and development biomass technologies into the commercial markets.

Among the non-technical barriers to successful deployment is the financial marketplace, which has great difficulty in accepting the real or perceived risks of commercializing a new technology. Financial barriers may in fact be the most challenging of the non-technical barriers to address. Although capital is critical to accomplishing the R&D for a biomass technology, those costs are miniscule compared to the financial requirements for testing and construction.

Figure 1 was prepared by the Office of Biomass Program (OBP) in the U.S. Department of Energy (DOE) to illustrate the increasing financial burdens that confront a project developer in deploying a new biomass technology.

OBP expanded its efforts to address the deployment problem by bringing together a number of finance, policy and industry experts

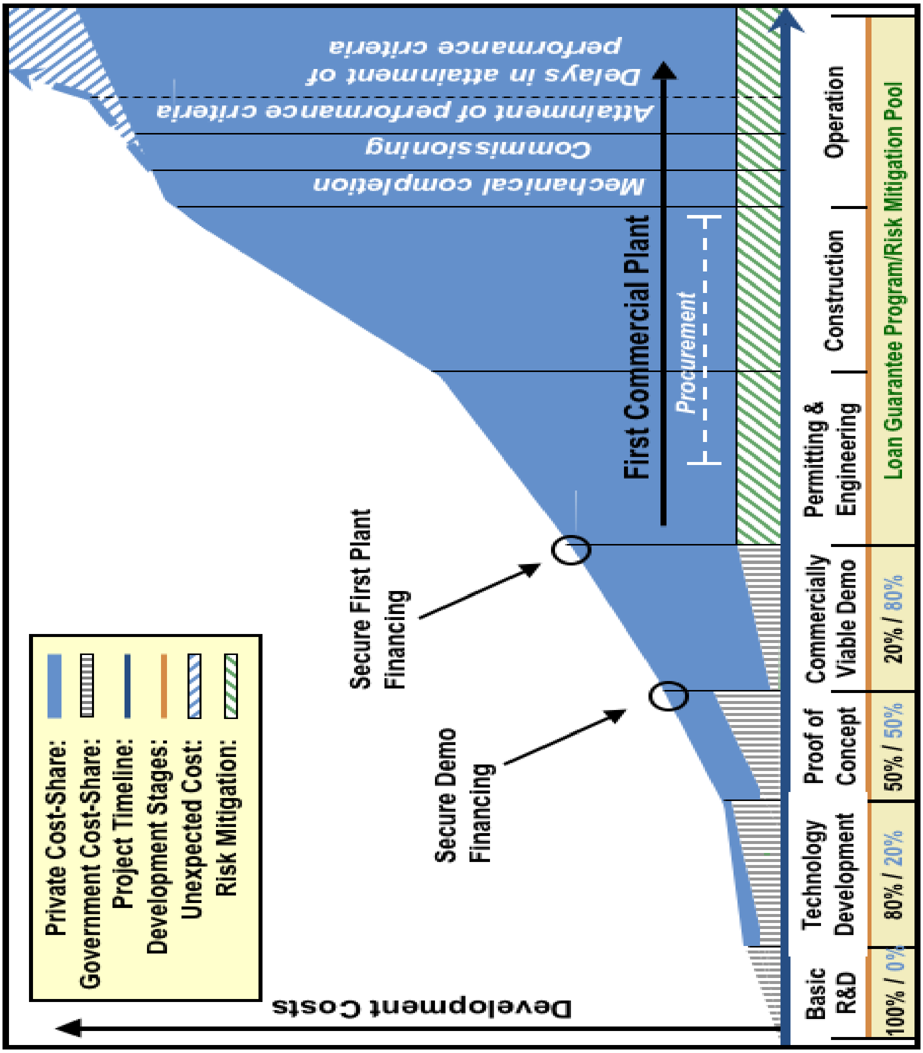
* *Roy Torkelson is an independent contractor to JP Morgan.*

to discuss the barriers from their points of reference and also to suggest ways to improve deployment success. The following represents the collective thinking of the group regarding the financial barriers facing developers of new technologies.

Financially, the most critical stages of the deployment process are **pilot-testing**, and building and operating **commercially viable demonstrations**. At the pilot-testing stage developers typically try to validate the technology. However, at the demonstration stage the developer wants to prove technology feasibility and profitability in a realistic setting. Ideally, the demonstration should indicate that the technology could cover its capital costs and provide a moderate margin of return on investment. However, during these stages capital requirements are high while investment is relatively low. Typically when constructing a commercially viable demonstration, capital costs are uncertain and contingency funds need to be available because the technology is not proven. At this stage investors are skeptical of the technology's market viability because it has yet to be proven. In addition, investors typically prefer a multitude of tests to ensure that the given technology will work under a variety of circumstances. Therefore, the ability of developers to progress from the R&D stage to commercialization is difficult, and thus the group recommended that DOE could serve a critical role in these stages.

If the DOE were to help finance and oversee a limited number (2-5) of similar projects from pilot-scale tests through commercially viable demonstrations through their program budget, developers could more quickly attain private capital and begin deployment. The pilot and demonstration scale plants must emulate the entire process being considered for a facility. They must also be able to be measured both in terms of technical efficiencies and economic viability. The most efficient and cost effective way of demonstrating the new technology would be by collocating on the grounds of an existing refinery for ethanol offtake or other ethanol production facilities rather than at a greenfield site. This would allow utilities and other common operations to be leveraged. It can also have an immediate positive effect on the existing plant's bottom line. Furthermore, with its understanding of investor expectations, DOE could ensure that

Figure 1 Risk Framework



entrepreneurs have the right people involved in developing test protocols to validate their technologies. Therefore, testing will be conducted in line with contractor and investor expectations of the technology's functionality, thereby reducing time and costs. Through the OBP budget, DOE could financially assist developers in this stage of the deployment process, helping them to overcome a major hurdle.

Once a commercially viable demonstration facility is proven to work, the next stage is to embark on the deployment of the **first commercially viable plant**. This is the stage at which developers need to secure an investment-grade EPC (Engineering, Procurement and Construction) contractor, finance engineering and construction (assuming non-recourse financing), finalize input and offtake contracts for the life of the facility debt, and have secured appropriate equity commitments from investors. It is the point at which capital demands are typically highest because investors still see high construction risk even for a demonstration-proven technology that is now being scaled up. By the construction stage, financing needs to be secured through an investor or private bank.

A modified loan guarantee program run by DOE to cover the construction period and the early years of operation was discussed among the experts and deemed to be ineffective unless it met certain criteria. First, any loan guarantee program must be limited to a finite period of time that will only provide guarantees during the project's riskiest periods. This time period must be set prior to the distribution of the loan. The loan guarantee must be gradually reduced and expire prior to the loan's payoff. In addition, the loan guarantee should be contingent on the review and approval of a team of independent engineers and financial consultants. The purpose of the review is to assess the technology and business plan to ensure that the loan will in fact help guarantee the successful and profitable launch of the technology. Furthermore, financial information needs to be reviewed to ensure that the project's cost has not been escalated solely to reduce entrepreneurial risk. The loan should account for only the construction and startup costs of the technology in accordance with good engineering practices. The objective of the loan guarantee should be to ensure the technology meets its performance criteria. Ultimately, the loan should cover approximately the first one to two years of the technology's deployment, following successful attainment of the performance guarantees, and should then gradually decrease in its coverage ratio over time. It is anticipated that the coverage ratios would shrink to zero at sometime between five and ten years following the passage of the performance criteria.

Another feasible solution would be for DOE to create a last resort risk mitigation pool for biomass technology developers, looking to other successful Federal programs, like the Transportation Infrastructure and Innovation Act (TIFIA), as a model. This would allow DOE to provide incremental financial guarantees during the commissioning and performance acceptance stages of the project through the first year of operation, thereby enabling developers to raise the necessary capital to proceed with development of their new biomass technology. This program could only be accessed when all other remedies have been exhausted and when the corrective action will result in a successful commercial launch. It was felt that a risk mitigation pool coupled with a successful demonstration project would be adequate to ensure successful deployment of the technology. However, a risk mitigation pool can also be used with a loan guarantee program to further accelerate technological deployment.

DOE would assess the level of severity of a given deployment barrier, assess the worthiness of the recipient, and issue financing. The developer would be required to pay a fee for the insurance guarantee including repayment of any draw on that insurance policy by a given period of time (typically following deployment). The money from the insurance premiums would be recycled back into the insurance program. Developers who apply to access the insurance program would first have to be approved by a team of independent engineers who determine whether the technical problem was unavoidable and then outline a cost estimate. Assistance would only be provided after a solution has been identified and reviewed by independent engineers.

Due to the considerable time, money and effort already invested in most of these projects, it is in the best interest of all parties (entrepreneurs, investors, contractors, markets, etc.) to overcome these hurdles and deploy these technologies. These suggested federal insurance guarantees should allow developers to successfully deploy their product and begin realizing revenue streams that not only support operations, pay debt service but also provide solid equity returns to their investors.

Table 1

Possible U.S. DOE Deployment Solutions
• Continue to provide 80/20 funding of technology development (**Current**)
• Continue to provide 50/50 funding of small-scale pilot-tests (**Current**)
• Provide 20/80 funding of critical large-scale demonstrations (**New**)
• Establish a loan guarantee program (**New**)
• Establish a pool for risk mitigation (**New**)

The recommendations in this document outline some logical steps to facilitating biomass technology deployment. Although DOE invested $93.9 M in biomass technology R&D in 2004, it is the fundamental objective of OBP to see that these technologies are ultimately deployed and "directly contribute to the creation of a new bioindustry to help reduce U.S. dependence on foreign oil by supplementing the use of petroleum for fuels and chemicals." Research and development issues have traditionally been the primary focus of DOE assistance and funding. However, it is clear that focusing on R&D alone will not lead to successful deployment.

The need to diversify the U.S. energy portfolio and to create a bioindustry as a means to this end is the reason these financial barriers must be addressed. Biomass clearly represents a viable option for displacing U.S. petroleum reliance, and these recommendations could be the next steps to ensuring its successful integration into the U.S. energy market.

Note: The information contained in this paper was derived from a white paper which was developed by members of USDOE's Office of Biomass Program and outside professionals, including the author, with expertise in project finance.

Ethanol: Lessons from Brazil

By David Sandalow

Ethanol is hot. In the United States, production increased by more than 20 percent in 2005. The nation's 97 ethanol plants are operating at close to full capacity, with another 33 plants under construction. Politicians from President George W. Bush to Senator Richard Lugar to Senator Barack Obama to Democratic National Committee Chair Howard Dean all support aggressive programs to promote ethanol.

Yet today ethanol provides only about 3 percent of the United States' transportation fuel. Few experts expect this figure to increase to more than 7 percent by 2010. In Brazil, in contrast, ethanol provides more than 40 percent of the fuel for transportation. Flex-fuel cars – capable of running on gasoline or ethanol – grew from less than 1 percent of the Brazilian new car market in 2001 to more than 70 percent today.

As the United States explores ways to reduce oil dependence, many observers are looking south for guidance. This paper summarizes the history of the Brazilian ethanol program, describes the program's current status and considers lessons for the United States from the Brazilian experience.

* *David Sandalow is Director of the Environment and Energy Project at the Brookings Institution.*

History

The early 1970's were a boom time in Brazil, with many observers heralding the "Brazilian economic miracle." Yet President Ernesto Geisel faced twin problems. First, the cost of Brazil's oil imports tripled in late 1973, due to the Arab oil embargo. Second, world sugar prices, which had been climbing upward since the mid-1960's, declined sharply in 1974.

Faced with these problems, Geisel launched the Brazilian National Alcohol Program in late 1975. The program was intended to reduce the need for oil imports and provide an additional market for Brazilian sugar. As a first step, the federal government immediately began promoting the production of ethanol for blending into gasoline, to the maximum extent feasible in existing vehicles (approximately 20 percent by volume).

In promoting ethanol, Geisel's government had many tools at its disposal. (Brazil's government during this era was both a central player in the nation's economy and a military dictatorship.) First, the government offered credit guarantees and low-interest loans for construction of new refineries. Second, a state trading enterprise began purchasing ethanol at favorable prices. Third, gasoline prices were set to give ethanol a competitive advantage. Fourth, a marketing program was launched, with the slogan "Let's unite, make alcohol." Finally, the state-owned oil company, Petrobras, began making investments for distribution of ethanol throughout the country.

The results were dramatic. Between 1975 and 1979, ethanol production increased more than 500 percent.

A second stage of the program was launched in 1979, when the Brazilian government signed agreements with major car companies to install assembly lines for 100 percent ethanol cars. Participating companies – including Fiat, VW, Mercedes-Benz, GM and Toyota – agreed to produce 250,000 ethanol-only cars in 1980 and 350,000 in

1982. A government program provided taxi drivers with incentives to convert their cars to 100 percent ethanol. Several leading race car drivers made highly visible use of 100 percent ethanol cars.

During the early 1980's, the Brazilian ethanol program flourished. With the help of government pricing policies, which kept the cost of ethanol to consumers significantly cheaper than the cost of gasoline, ethanol production more than tripled between 1979 and 1985. A World Bank loan helped cover costs of the program. By the mid-1980's, ethanol made up roughly half of Brazil's liquid fuel supply.

In 1985, however, Brazil's ethanol program began to experience problems. World oil prices dropped sharply in 1985-86, reducing the immediate benefit of replacing oil imports with ethanol. At the same time, Brazil faced serious inflation problems and began a series of difficult economic reforms. As part of a broader cut back on subsidies, the price differential between ethanol and gasoline was eliminated, soft loans for the construction of new refineries were cut, and support for the ethanol program from state trading companies was slowed and then stopped.

These changes had a significant impact on ethanol production, which stagnated. By the late 1980's ethanol production even began to decline slightly, as world sugar prices rose and export markets for refined sugar became more profitable.

Yet these trends in ethanol production had little immediate impact on Brazilian automakers, which continued to manufacture ethanol-only cars in increasing amounts. By the late 1980's, almost all new cars in Brazil were made to run on ethanol only. The result was a serious shortage of ethanol in 1990. In a rich irony, Brazil was forced to import ethanol and turn to methanol blends to keep cars on the road.

Political support for the ethanol program evaporated. Brazilian auto manufacturers quickly retooled to build gasoline cars. By the mid-1990's, only fleet vehicles (such as taxis and rental cars) were being made to run on ethanol.

The 1990's were a quiet decade for Brazil's ethanol program. With deregulation and privatizations underway throughout the Brazilian economy, and world oil prices low, there was little political support for returning to programs of the kind that helped build Brazil's ethanol infrastructure during the 70's and 80's. Nevertheless, throughout this period, the national government continued to require that all gasoline sold in Brazil contain roughly 20 percent ethanol by volume.

As the decade progressed, some Brazilian engineers and policymakers showed increasing interest in flex-fuel vehicles of the kind being built by U.S. manufacturers seeking credits under the CAFE law. Toward the end of the 1990's, several auto manufacturers began talking with the Brazilian government about manufacturing flex-fuel vehicles for the Brazilian market.

In 2001, the Brazilian government agreed to treat flex-fuel vehicles as ethanol-fueled, entitling FFV's to preferential tax treatment (a 14 percent sales tax, as compared to a 16 percent sales tax on non-ethanol cars). Ford launched the first flex fuel prototype in 2002, with VW following in 2003.

Brazilian Ethanol Program Today

Today ethanol provides roughly 40 percent of transportation fuels in Brazil, a higher percentage by far than in any other nation. In 2005 Brazil produced just over 4.23 billion gallons of ethanol, roughly the same as the United States (which produced 4.26 billion gallons).

The most dramatic development in the Brazilian ethanol program in recent years has been the explosive growth of flex-fuel vehicles. In November 2004, FFV's represented 30 percent of new car sales in Brazil. For calendar year 2005, the figure was 53 percent. In February 2006, more than 70 percent of new cars sold in Brazil were flex-fuel.

Production costs for ethanol in Brazil are the world's lowest. UNICA, the industry trade association, estimates average production costs of approximately US$0.80 per gallon. (Estimates of costs in the U.S. vary from US$0.90 - US$1.30 per gallon.) A favorable climate, low labor costs and mature infrastructure built up over several decades are among the factors producing this advantage.

The Brazilian government's principal intervention on behalf of its ethanol industry is the requirement that all gasoline sold contain a minimum percentage of ethanol. This blending ratio is currently set at just over 20 percent. In addition, the government provides a slight tax preference for the purchase of new flex-fuel cars (14 percent sales tax, as compared to a 16 percent sales tax on gasoline-only vehicles, as noted above). Brazil maintains a 30 percent tariff on imports of ethanol and 20 percent tariff on imports of sugar. Government price-setting for ethanol in Brazil was phased out during the 1990's.

Brazil is currently courting export markets for ethanol, focusing on Asia and North America. Petrobras recently signed a deal with Mitsui to pursue study ethanol logistics for the Japanese market.

The ethanol industry enjoys widespread political support in Brazil today. The industry takes credit for more than 1.8 million jobs in Brazil and for replacing, since 1976, more than 1.44 billion barrels of oil. Brazilian ethanol refineries generate their own process heat and electricity from portions of the sugar crop known as "bagasse," with many refineries selling surplus electricity into the grid. Ethanol contributes significantly to improving air quality in Sao Paolo and to cutting emissions of heat-trapping gases from the Brazilian transport sector.

In March 2006, ethanol prices reached record highs due to sharp increases in global prices for refined sugar. In response, the government reduced the mandated blending ratio from roughly 25 percent to 20 percent. Possible supply shortages are looming, as sugarcane growers divert ethanol feedstock to the refined sugar market. With oil prices also reaching record highs, market analysts differ with regard to likely growth trajectories for Brazil's ethanol industry in the months and years ahead.

Lessons for United States

Brazil and the United States share many characteristics. Both are continent-sized countries. Both are agricultural powerhouses. Both have mature domestic automobile industries.

There are many differences between the two countries, of course. Brazil's climate is warmer. Brazil's wage rates are lower. Cultural attachments to the automobile are different in each country. Brazil's government, until recently, owned key industries and set prices throughout the economy.

With these comparisons as background, what lessons can the United States draw from Brazil's ethanol program? I suggest five.

First, rapid expansion of ethanol production capacity is possible with government support. Matching the growth rates in the Brazilian industry during the 1970's – when ethanol production grew 500 percent from a small base in just a few years – is not a realistic objective. But the Brazilian experience suggests several policy tools that could be used in the U.S. today. Credit guarantees and low-interest loans such as those used in Brazil could help speed construction of the first generation of commercial cellulosic ethanol plants. (The Energy Policy Act of 2005 includes authorization for such programs, though Department of Energy guidelines and appropriations are needed to make those programs a reality.) Mandates for blending ethanol into the fuel supply – part of the Brazilian program since its inception – can provide powerful signals to producers and help promote rapid growth in capacity.

That said, we should be careful in drawing conclusions about rapid supply expansion from the Brazilian experience of the 70's. Several subsidies provided by the Brazilian government in that era – such as infrastructure investments by a state-owned oil company – could not be duplicated in the U.S. today. Rather than look for ways to duplicate policies of the Brazilian government 30 years ago, we should identify the specific objectives of those policies and ask how these objectives could best be achieved under current conditions. In the absence of a state-owned oil company, for example, how should the cost of converting distribution infrastructure (such as service station tanks) best be funded? If promoting rapid expansion of ethanol consumption is our larger goal, we need to devise a uniquely U.S. answer.

A **second** lesson from Brazil – consistency counts. Perhaps the most important part of Brazil's ethanol program over the past three decades has been the requirement that ethanol make up a certain percentage of the fuel supply. The Brazilian government has used this requirement to help control the ethanol market, varying the percentage somewhat depending on market conditions. Yet even during periods of relatively modest political support for the ethanol program, such as the 1990's, the requirement did not disappear. This was important in sustaining the industry through hard times.

A **third** lesson – any ethanol program must anticipate commodity price swings. Enthusiasm for ethanol is always highest when oil prices are high and sugar prices low. Yet the relative prices of oil and sugar will vary with time.

One essential way to prepare for price swings is with flex-fuel vehicles. The explosive growth of FFV's in Brazil during the past few years is a hopeful sign – both about the ability of auto companies quickly to scale up production and the instant acceptance of such cars by consumers. Precisely because commodity prices will vary, as Brazil saw in the '80's, a vehicle fleet in which FFV's predominate is essential to a successful long-term ethanol program

Fourth, public attitudes change quickly. In the 1970's and early 1980's, enthusiasm for ethanol in Brazil was high. In the late 80's and early 90's, public support collapsed with astonishing speed amidst shortages in supply. In the past several years, enthusiasm climbed steeply with higher oil prices and flex-fuel cars. Policymakers should anticipate and plan for significant short-term swings in public attitudes on ethanol, in response to market conditions and other factors.

Finally, ethanol technologies improve steadily with time. This is true of almost all technologies, but the Brazilian experience of the past 30 years provides some compelling data when it comes to ethanol. Between 1975 and 2000, production of ethanol per hectare in Brazil more than doubled. During the same period, harvesting costs fell by half. We can anticipate similar improvements if the U.S. ethanol industry grows substantially – staying “hot” – in the years ahead.

List of Participants

Co-chairs:

Thomas W. Ewing
Chair. USDA-DOE Biomass Advisory Committee
US Congressman, 1991-2001
Pontiac IL

R. James Woolsey
Vice President
Booz Allen Hamilton
McLean VA

Ghassem R. Asrar
Deputy Administrator
Agricultural Research Service
Beltsville MD

Loren K. Beard
Senior Manager
Environmental and Energy Affairs
DaimlerChrysler
Auburn Hills MI

Neil Brown
Professional Staff (Majority)
Foreign Relations Committee
U.S. Senate
Washington DC

Bruce Dale
Professor
Department of Chemical Engineering and Materials Science
Michigan State University
East Lansing MI

Michael Dennis
President and CEO
BC International
Dedham MA

Reid Detchon
Executive Director
Energy Future Coalition
United Nations Foundation
Washington DC

William A. Frey
Global Business Leader
Du Pont Bio-Based Materials
Wilmington DE

Jackie J. Gleason
Acting Administrator
Rural Development Business & Cooperative Programs
US Department of Agriculture
Washington DC

Nathanael Greene
Senior Policy Analyst
NRDC
Natural Resources Defense Council
New York NY

Michael Griffin
Executive Director, Green Design Institute
Carnegie Mellon University
Pittsburgh PA

Richard Hamilton
President and CEO
Ceres, Inc.
Thousand Oaks CA

Jack Huggins
Watershed Program Director
The Nature Conservacy
Peoria IL

Douglas E. Kaempf
Program Manager
Office of the Biomass Program
U.S. Department of Energy
Washington DC

Vinod Khosla
Kleiner Perkins Caufield & Byers
Menlo Park CA

William E. Lee
General Manager
Chippewa Valley Ethanol Company
Benson MN

Jason Mark
Vehicles Director
Union of Concerned Scientists
Berkeley CA

Lori A. Perine
Executive Director
Agenda 2020 Technology Alliance
American Forest & Paper Association
Washington DC

Peter Reiling
Vice President for International and Policy Programs
The Aspen Institute
Washington DC

Jerome Ringo
The Apollo Alliance
Washington DC

David Sandalow
Director, Environment & Energy Project
Brookings Institution
Washington DC

Christopher Schepis
Legislative Representative
National Farmers Union
Washington DC

Ernest C. Shea
President
Natural Resources Solutions LLC
Lutherville MD

Anne Simmons
House Committee on Agriculture
Washington DC

J. Read Smith
Grain and cattle producer
Co-chair, Ag Energy Work Group
St. John WA

Don J. Stevens
Senior Program Manager
Energy Science and Technology Directorate
Pacific Northwest National Laboratory
Richland WA

Matt Thornblad
Legislative Assistant
Senator Tim Johnson
Washington DC

Stephen R. Tolman
Chief Executive Officer
National Corn Growers Association
Chesterfield MO

Roy Torkelson
Independent Contractor
JP Morgan
New York NY

Alan Weverstad
Executive Director of Environment & Energy
General Motors
Detroit MI

Staff:

John A. Riggs
Executive Director
Program on Energy, the Environment and the Economy
The Aspen Institute
Washington DC

David W. Monsma
Rapporteur
Associate Director
Program on Energy, the Environment and the Economy
The Aspen Institute
Washington DC

Katrin Thomas
Program Manager
Program on Energy, the Environment and the Economy
The Aspen Institute
Washington DC

Selected Aspen Institute Publications

The New Energy Security

The first annual Forum on Global Energy, Economy and Security was held in October, 2005. Co-chaired by James R. Schlesinger, former US Secretary of Defense and Energy, and Luis Giusti, Senior Advisor at CSIS and former CEO of Petroléos de Venezuela, the Forum discussed recent increases in oil and gas prices, global competition for reserves, whether oil production will peak soon, growth in demand in China and India, prospects for increased production in Saudi Arabia and Russia, US reliance on LNG imports to meet demand growth, and the links between globalized energy markets and perceptions of national security.

2006. 55 pages, ISBN#89843-442-4, $ 12 per copy

Electricity: Who Will Build New Capacity?

The report of the 2005 Energy Policy Forum, chaired by Cinergy Corp. Chairman and CEO James E. Rogers, examines who will build needed new power generation and transmission facilities in a new regulatory environment. The report is organized around recommendations on market design, energy efficiency, innovation and technology choice, carbon management, and infrastructure security.

2005. 46 pages, ISBN# 89843-440-8, $ 12 per copy

A Silent Tsunami: The Urgent Need for Clean Water and Sanitation

Based on a 2005 dialogue co-sponsored by the Aspen Institute and the Nicholas Institute for Environmental Policy Solutions at Duke University, this report provides a series of recommendations for governments, businesses, and other organizations. Co-chairs William K. Reilly and Harriett C. Babbitt highlight the urgency of the challenge and the array of public and private initiatives to tackle it.

2005. 40 pages, ISBN# 0-89843-435-1, $ 12 per copy

Conserving Biodiversity

Co-chaired by Bruce Babbitt, former U.S. Secretary of Interior, and José Sarukhán, Professor of Ecology and former President of the National University of Mexico (UNAM), this 2004 dialogue was based on commissioned discussion papers and focused primarily on the policy drivers of ecosystem degradation and biodiversity loss. This report seeks to educate policy makers and opinion leaders on the loss of critical ecosystems and biodiversity and to recommend specific changes in policies that may affect biodiversity, such as trade, aid, and lending policies.

2004. 120 pages, ISBN# 0-89843-423-8, $ 16 per copy

A Climate Policy Framework: Balancing Policy and Politics

The Aspen Institute, in association with the Pew Center on Global Climate Change, convened a diverse group of leaders to develop a politically feasible framework for a mandatory U.S. climate change policy. Co-chaired by Eileen Claussen and Robert W. Fri, the group did not discuss *whether* mandatory action is now warranted. It did, however, reach consensus on several fundamental elements of a national policy, *if* one is adopted.

2004. 100 pages, ISBN# 089843-397-5, $8 per copy.

Tackling the Critical Conundrum: How Do Business, Government and Media Balance Economic Growth and a Healthy Environment?

Former EPA Administrator Christine Todd Whitman and former Undersecretary of State Frank Loy co-chaired a Forum in Aspen on balancing economic growth and a healthy environment. This report includes their conclusions and discussion papers exploring the tradeoffs from the perspectives of business leaders, elected officials, investment firms, journalists, and economists.

2004. 102 pages, ISBN# 089843-435-1, $12 per copy.

Fossil Fuels, the Hydrogen Economy, and Energy Policy

The 28th annual Energy Policy Forum considered key variables affecting supply and demand for each of the fossil fuels, domestically and globally, including new technologies and the competition offered by alternatives such as renewables and nuclear. It then examined the problems and potential of hydrogen, including its primary fuel source. Finally, based on these discussions, it suggested guidance for the development of near-term government energy policy. Red Cavaney, President and CEO of the American Petroleum Institute, and Susan Tomasky, Executive Vice President and CFO of American Electric Power Company, co-chaired the Forum.

2004. 62 pages, ISBN# 0-89843-422-X, $8 per copy.

Electricity Restructuring

The 2003 Energy Policy Forum focused on electricity restructuring. Chaired by former Director of Central Intelligence and Undersecretary of Energy John Deutch, participants discussed the advantages and disadvantages of national rules governing transmission, economic and market power issues affecting ownership, whether the market's choice of fuel is in the national interest, whether natural gas supplies are adequate, and how restructuring will affect the future of nuclear power, renewables, efficiency, and distributed generation. A series of Electricity Recommendations were sent to Congressional and Administration leaders following the Forum.

2003. 55 pages, ISBN#: 0-89843-389-4, $8 per copy.

U.S. Policy on Climate Change: What Next?

Following U.S. withdrawal from the Kyoto Protocol, the Aspen Institute invited a distinguished group of scientists, business leaders, and environmental experts to discuss what the U.S. should do next. The non-technical discussion papers provide useful background and innovative policy suggestions. Forum co-chairs Frank Loy, Undersecretary of State under President Clinton, and Bruce Smart, Undersecretary of Commerce under President Reagan, summarize the discussion and the Forum's conclusions in a compelling introductory essay. The group concluded that the U.S. government needs to send a signal now that carbon emissions will have a cost in the future.

2002. 200 pages, ISBN# 0-89843-344-4, $16 per copy.

Dam Removal: A New Option for a New Century

This report offers a series of recommendations and practical advice to make it easier to integrate the consideration of dam removal into river management decisions, and to evaluate fairly and, if appropriate, to implement dam removal effectively. It is the product of a two-year dialogue among a group of people who represent a wide range of interests and disciplines. The imprimatur of this diverse group, with interests that are often at odds, lends a unique weight to the wide-ranging and practical recommendations.

2002. 68 pages, ISBN# 0-89843-360-6, $12 per copy.

U.S. Policy and the Global Environment: Memos to the President

Prior to the 2000 election the Aspen Institute convened a distinguished group of leaders as a hypothetical committee to advise the new President on global environmental policy. Experts prepared this set of policy memos to tell the President, concisely and in understandable language, "what he should know" and "what he should do" about climate change, biodiversity, population, oceans, water, food and agriculture, and other problems. A thematic summary of the group's conclusions, written by co-chairs Donald Kennedy of Stanford University and Roger Sant of the AES Corporation, communicates the urgency of the challenges, the complexity of the interrelated issues, and the optimism necessary to tackle them.

2000. 220 pages, ISBN#0-89843-303-7, $16 per copy.

With All Deliberate Speed: Electricity Restructuring in Asia

The 1999 Pacific Rim Energy Workshop was held in Kanagawa, Japan, co-sponsored and hosted by The Asia-Pacific Energy Research Centre (APERC), the energy research arm of the Asia Pacific Economic Council (APEC). Representatives of 17 countries or economies discussed electricity restructuring and fuels trade in the region. This report of the meeting concludes that the theoretical and observed benefits or deregulation are quite powerful, but there are concerns about the impacts of making the transition from national monopoly systems to deregulated or privatized systems.

1999. 23 pages, ISBN#0-89843-278-2, $8 per copy.

To order any of these reports, contact:
The Aspen Institute Publications
Phone: (410) 820-5433 • Fax: (410) 827-5928
publications@aspeninstitute.org
